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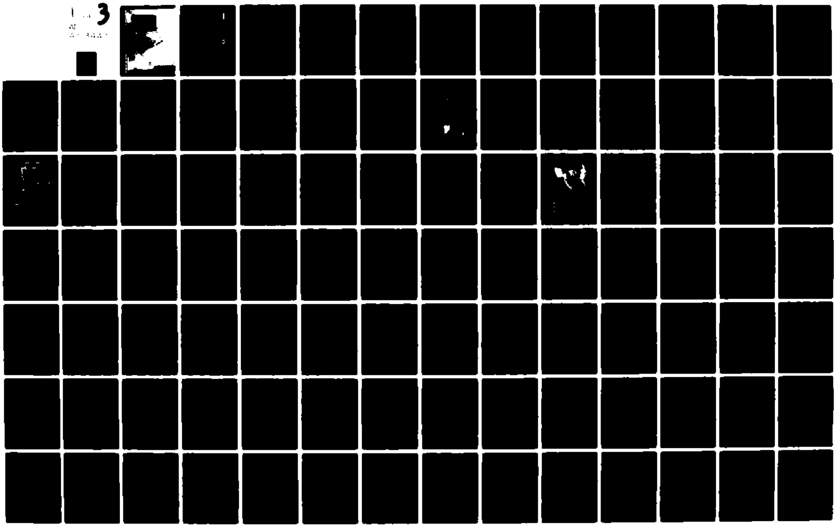

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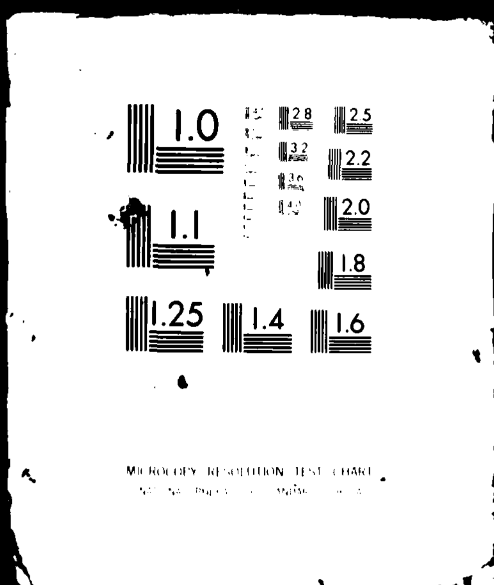

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MX SITING INVESTIGATION
GEOTECHNICAL EVALUATION OF
LUKE BOMBING AND GUNNERY RANGE
GEOTECHNICAL REPORT
LECHUGUILLA DESERT, ARIZONA
VOLUME I

Prepared for:

Space and Missile Systems Organization (SAMSO)
Norton Air Force Base, California

Prepared by:

Fugro National, Inc.
3777 Long Beach Boulevard
Long Beach, California 90807

20 January 1978

FUGRO NATIONAL, INC.

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report presents results of a geotechnical investigation that was performed in Lechuguilla Desert, Luke Bombing + Gunnery Range, Arizona. [illegible] basic data [illegible] seismic [illegible] electrical [illegible] and soil [illegible]

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FOREWORD

This report was prepared for the Department of the Air Force, Space and Missile Systems Organization (SAMSO) in compliance with conditions of Contract No. F04704-77-C-0010, and is a geotechnical report of Lechuguilla Desert in southwestern Arizona.

This report presents the objectives, scope, study approach, and results of an interdisciplinary field investigation as part of the Methodology Study for deploying the MX Land Mobile Advanced ICBM system. This report was prepared under the directin of Kenneth L. Wilson, Project Director and under the supervision of the following Project Managers; V. Reid McLamore, Geophysics; Robert J. Lynn, Geology; Stanley H. Madsen, Engineering. Project level personnel responsible for conduct of thefield work, data analysis, and report writing include Dale Hennon, Robert LaRue, Owen Swanson, and Avram Ninyo.

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GEOPHYSICAL PROCEDURES

1.0 INTRODUCTION

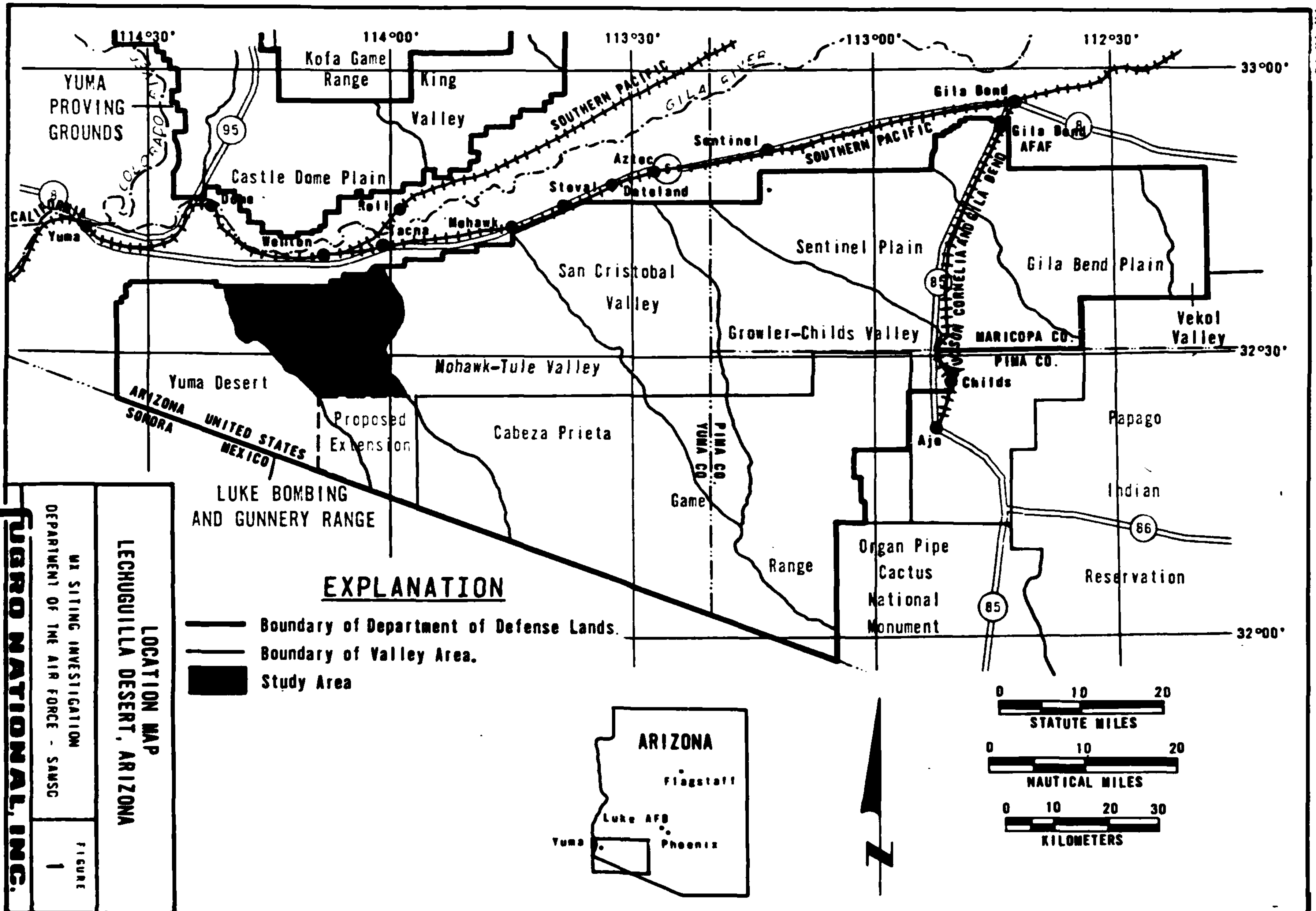
1.1 BACKGROUND AND OBJECTIVES

This report presents the results of a geotechnical investigation that was performed in Lechuguilla Desert, Luke Bombing and Gunnery Range (LBGR), Arizona. It is identified as FN-TR-19 (Fugro National Technical Report No. 19) and is the second technical report based on extensive field work for the MX siting program. Mohawk-Tule Valley (FN-TR-18) was the first of two adjacent Valleys in LBGR to be investigated during FY 77 as part of MX Methodology Studies and is located east of Lechuguilla Desert (Figure 1). The two Valleys in LBGR were selected for Methodology Studies because of the similarities with many other Basin and Range Valleys, their relatively high overall geotechnical siting suitability, and the ready access afforded by the U.S. Air Force and U. S. Marine Corps. The separate geotechnical reports prepared for Mohawk-Tule Valley and Lechuguilla Desert will be followed by a final Methodology Report. Each geotechnical report presents data similar to the type necessary for the documentation of the validation of a Candidate Deployment Parcel.

The primary objectives of this report are to present the geotechnical data obtained during the investigation of Lechuguilla Desert, and to provide our conclusions relative to the evaluation of the suitability of Lechuguilla Desert for MX deployment. In combination with future studies, this information will be used in preparing a Characterization "Working Paper" for the Sonoran CSP. Information from Fine Screening and the Characterization studies

of all Candidate Siting Provinces will be used to define and rank all the Candidate Siting Regions. Validation Studies will begin only in those highest ranking Candidate Siting Regions with the ultimate objective of selecting the most suitable Candidate Deployment Parcels for the MX system.

Another objective of this report is to present a summary of the relative effectiveness of the investigative techniques used to obtain the geotechnical data; i.e., a methodology evaluation. The overall objective of the forthcoming comprehensive Methodology Report is to thoroughly evaluate the cost effectiveness of all the technique used in order to determine the most cost effective and efficient mix of geotechnical investigative methods (from the disciplines of soils engineering; engineering geology and geophysics) to meet the requirements for MX Validation, and site-specific studies.



LOCATION MAP
LECHUGUILLA DESERT, ARIZONA

MX SITING INVESTIGATION
DEPARTMENT OF THE AIR FORCE - SAMSC

FIGURE
1

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1.2 APPROACH

The geotechnical data presented in this report were obtained applying a blend of proven investigative techniques, combining the disciplines of engineering geology, soils engineering, and geophysics to satisfy the objectives of the Methodology program which requires an evaluation of each of the techniques and the kinds of data obtained. To achieve this, some redundant data collection techniques were utilized. For example, to a degree, basin shape and materials layering can be determined from aeromagnetic, gravity or seismic refraction surveys. Besides acquiring constructibility and Vulnerability and Hardness (V and H) data, each method can be evaluated and ranked in terms of its relative accuracies and cost benefits for use in similar geotechnical environments. The ultimate result is the development of a somewhat standard geotechnical investigation suitable for efficiently and rapidly obtaining sufficient geotechnical data over large potential MX siting areas.

Regional and site-specific techniques were used. Aeromagnetic, ground magnetic and gravity surveys, and aerial photograph interpretation and field mapping provide regional-type information. Site-specific techniques, such as refraction surveys, provide "line" information, and other field activities such as drilling and trenching, provide "point" information (Drawing 1; in pocket). By combining these point, line, and regional techniques, data can be extrapolated over a designated area. One such example is the extrapolation of soil properties determined from laboratory tests on boring or trench samples to larger areas defined by geologic units.

1.3 REPORT FORMAT

The report is divided into Sections 2.0 through 5.0, Appendices A through C and an Appendix Supplement. Section 2.1 through 2.4 contains, in brief form, results and conclusions based on the integration of the best available data obtained in Lechuguilla Desert from each of the three disciplines of geophysics, engineering geology, and soils engineering. Section 2.5 rates the effectiveness of the techniques utilized during the investigation. Sections 3.0, 4.0, and 5.0 cover the objectives, scope, and results from the geophysical, engineering geology, and soils engineering studies, respectively. In these sections, all information is based almost entirely on data derived from the individual disciplines being discussed. The Glossary of Terms and the Bibliography, respectively follow Section 5.0. In-text graphics consist of figures and tables immediately following (where possible) the page of first mention, and large folded drawings (1, 2, and 3) located in a pocket following the Bibliography.

The three appendices (A, B, and C) and the appendix supplement (D) present support data. Appendices D, E, and F, which discuss field and laboratory procedures, were included in the Mohawk-Tule Geotechnical Report (FN-TR-18) and are not repeated here.

2.0 VALLEY CHARACTERISTICS

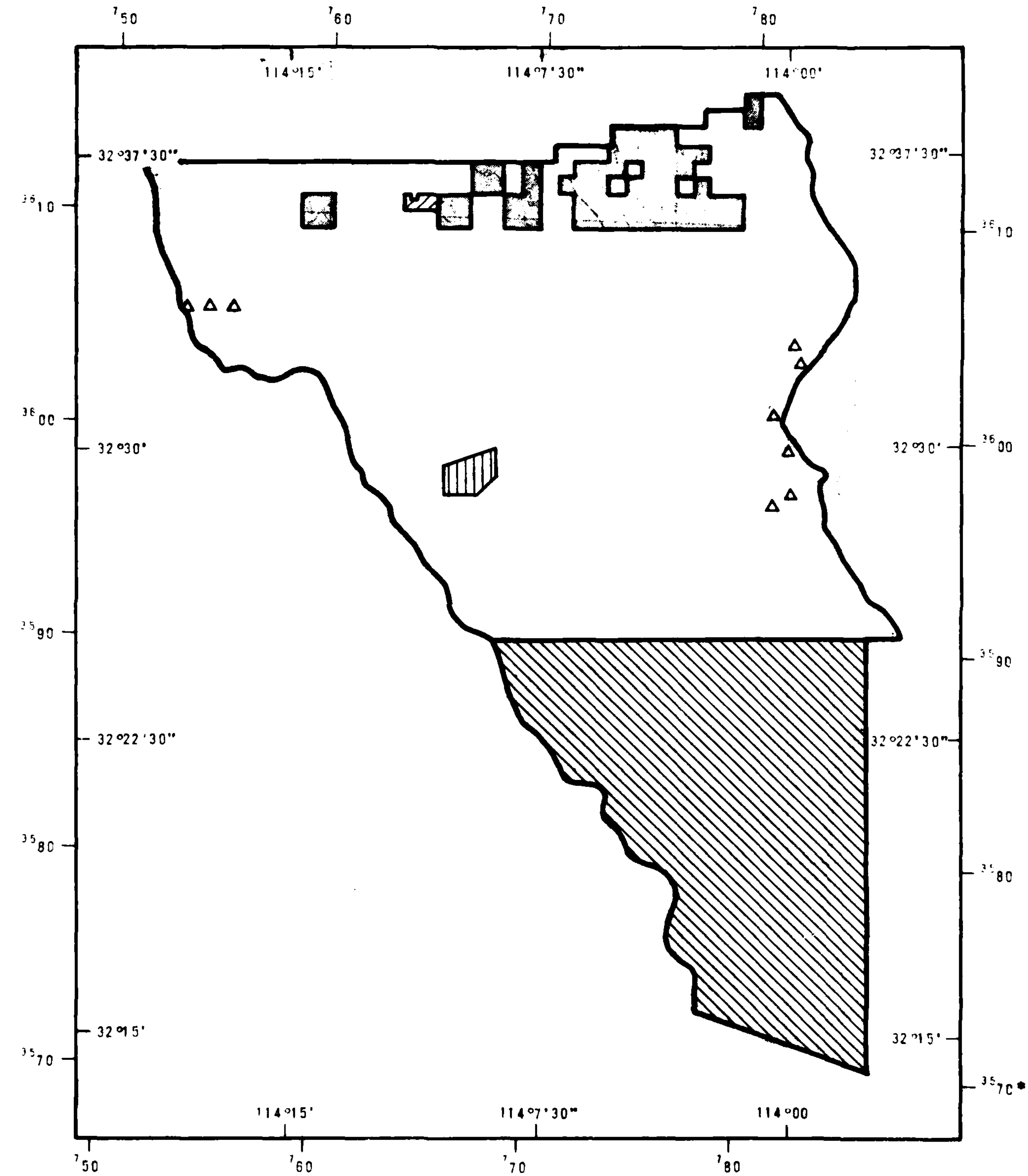
2.1 SETTING

2.1.1 OWNERSHIP AND LAND USE

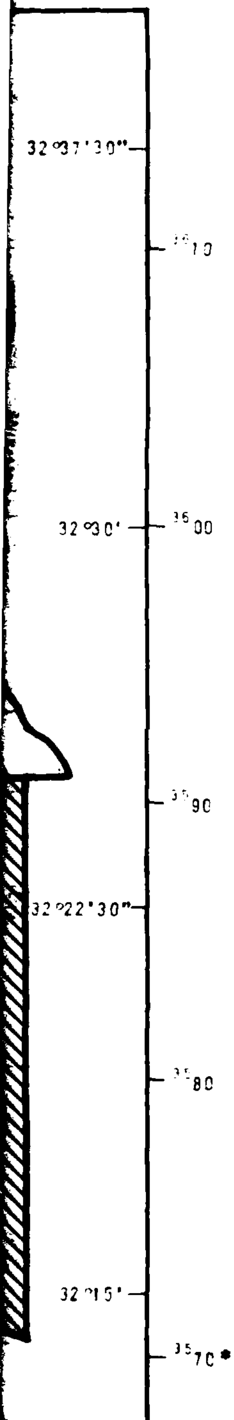
Lechuguilla Desert encompasses portions of segments five, six and eleven of LBGR (U.S.Department of the Air Force, 1973; updated 1976). As defined in FN-TR-3 (1975c), Lechuguilla Desert included land within the Cabeza Prieta Game Refuge (Figure 1). This investigation covers only that portion of the Valley north of the proposed Cabeza Prieta Game Refuge Extension boundary.

Department of Defense use of Lechuguilla Desert was originally established by Public Land Orders 56 (1942) and 97 (1943). These were later terminated under Executive Order 9526 and re-established under Public Law 87-597. The land is controlled and administered by the Yuma Marine Corps Air Station, Yuma, Arizona.

Ownership of the 166 square nautical miles (nm^2) or 569 square kilometers (km^2) of Lechuguilla Desert is divided among federal and state government agencies and private owners (Figure 2). The Bureau of Land Management (BLM) owns 153 nm^2 (525 km^2) of land in the Valley. State-owned land covers 12 nm^2 (41 km^2) principally in the northern part of the Valley. Privately owned land covers 0.5 nm^2 (1.5 km^2) along the northern border. Nine private mining claims of 21 (0.1 km^2) acres each are located in portions of nine sections in the Gila and Copper Mountains (Figure 2).

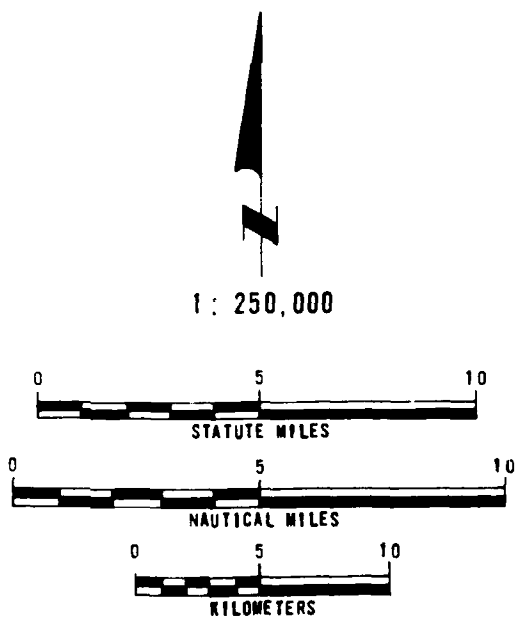


750
760
770
780
114°15'
114°7'30"
114°00'
32°37'30"
3610
3600
32°30'
3590
32°22'30"
3580
32°15'
3570



EXPLANATION

- Department of the Interior Bureau of Land Management
- State of Arizona
- Private
- Have Host test site; USAF
- Proposed extension; Cabeza Prieta game refuge
- △ Unpatented Mining Claim (private)
- Lechuguilla Desert Boundary



*NOTE: See Appendix page C-5 for explanation of Universal Transverse Mercator Grid System.

OWNERSHIP AND LAND USE MAP, LECHUGUILLA DESERT, ARIZONA

MX SITING INVESTIGATION DEPARTMENT OF THE AIR FORCE - SAMSO	FIGURE 2

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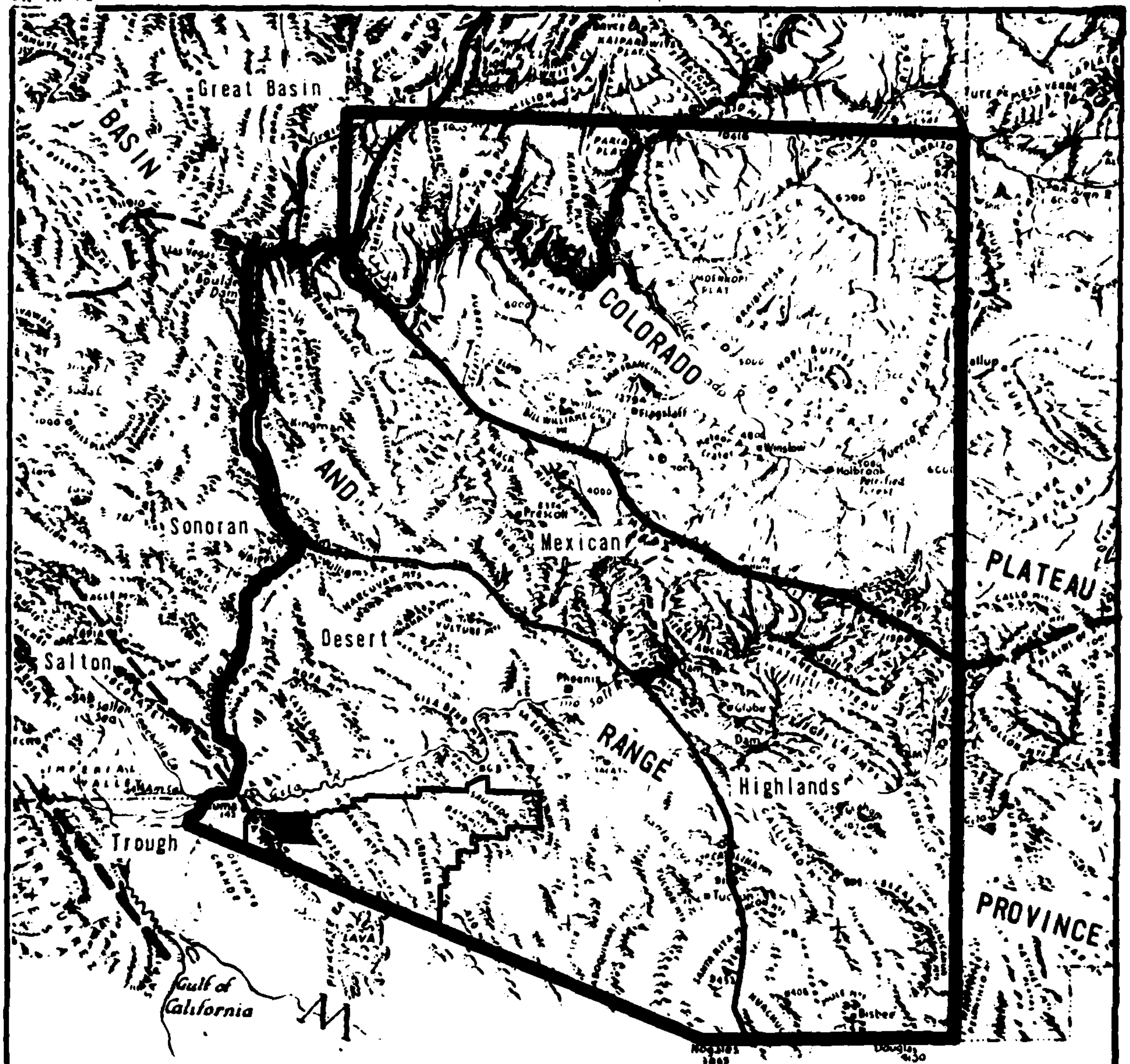
2.1.2 PHYSIOGRAPHY

Lechuguilla Desert lies within Yuma County, Arizona, 22 nm (75 km) east of Yuma in LBGR. The Valley is characterized by irregular, generally north to northwest trending fault-block mountains separated by a broad alluvial basin interrupted in the northern portion by the Wellton Hills, and lies within the Sonoran Desert section of the Basin and Range Physiographic Province (Figure 3). The Valley is bounded on the west by the Gila Mountains and on the east by the Baker Peaks and Copper Mountains (Drawing 2; in pocket). In plan view, the Valley is trapezoidal shaped; the east and west sides are 15 and 16 nm (28 and 30 km) in length respectively, while the north and south sides are 16 and 12 nm (30 and 22 km) in length respectively (Drawing 2). Mid-Valley lengths are 12 nm (22 km) in a north-south direction and eight nm (15 km) in an east-west direction.

The Gila Mountains rise abruptly to a sharp, linear crest striking approximately north 20 degrees west (N20W), with a maximum elevation of 3156 feet (963 m). The Baker Peaks and Copper Mountains on the east side of the Valley rise less abruptly, have a broad, irregular northward trending crest, and have a maximum elevation of 2888 feet (880 m). Differences in physiography are the result of a combination of lithologic changes (metamorphic versus igneous) and structural controls (joints, fractures, and faults) (Section 2.1.3). Maximum overall valley relief is 2780 feet (848 m) from Sheep Mountain in the Gila Mountains to the northern lowland area. Maximum relief is 1025 feet (312 m) from the highest mapped alluvium (Cipriano Pass) in the south to Coyote Wash in the north.



EXPLANATION

Lechuguilla Desert, Arizona

Boundary of Physiographic Province. Dashed where approximate.

Section boundary of Physiographic Province. Dashed where approximate

Boundary of Luke Bombing and Gunnery Range

0 50 100 STATUTE MILES

0 50 100 NAUTICAL MILES

0 50 100 KILOMETERS

PHYSIOGRAPHIC DIVISIONS OF ARIZONA LECHUGUILLA DESERT, ARIZONA	
MX SITING INVESTIGATION DEPARTMENT OF THE AIR FORCE - SAMSO	FIGURE 3

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Relief from south to north along the Valley axis along Coyote Wash is 475 feet (119 m) over a distance of 16 nm (30 km).

The basin separating the Copper and Gila Mountains is filled with deposits shed from these mountains and the Wellton Hills which divide the Valley in the north and separate the converging north-flowing drainage system (Drawing 2). West of Wellton Hills a three to five nm (6 to 9 km) wide, gently sloping (1.2 to 1.4 percent) alluvial plain flanks the Gila Mountains. East of the Wellton Hills and Coyote Wash, the alluvial plain flanking the Copper Mountains is three to six nm (6 to 11 km) wide and slopes approximately 0.8 percent toward the northwest (Table 5; Section 4.4.8). South of the Wellton Hills, the alluvial plains converge at Coyote Wash to form an unobstructed basin approximately nine nm (17 km) wide. Slopes in this area generally range from 0.9 to 1.4 percent (Drawing 2). Stream densities range from 0 to 25 per nautical mile throughout the Valley (Section 4.7.1.2).

2.1.3 GEOLOGY

The north central Copper Mountains, Wellton Hills and northern Gila Mountains are composed principally of metamorphic rock (gneiss and schist), while intrusive igneous rock (quartz monzonite) predominates in the southern portions of the Copper and Gila Mountains (Drawing 2). These units are of pre-Cretaceous age. The quartz monzonite was encountered at a depth of 510 feet (156 m) in Boring LD-D-3 (Drawing 1). Pegmatite dikes within metamorphic rock average six inches (150 mm) in width and greater than 50 feet (15 m) in length. Similar dikes within intrusive igneous rock tend to be narrower and less concentrated.

At the north end of the Copper Mountains, Baker Peaks consist of arkosic sandstone and a granite-gneiss boulder conglomerate of probable Tertiary age.

Geophysical (gravity) and geomorphic data (linearity of the fronts of the Gila and southern Copper Mountains) indicate a fault bounded basin, probably a horst and graben structure. Structural control of the northwest Valley margin is indicated by the west-northwest trending Sheep Mountain Fault. No faults displacing surficial basin-fill deposits were observed within the Valley proper; however, photolineaments associated with the Sheep Mountain Fault are suggestive of such occurrences along the mountain fronts. Discussion and analysis of the seismicity of south-western Arizona was presented in FN-TR-3 (1975c).

Geophysical survey data (aeromagnetic and ground gravity) show the Lechuguilla Desert to be an assymetrical basin, deepening to both the south and north of the shallow rock surrounding the Wellton Hills. High frequency aeromagnetic data indicates the probable occurrence of shallow igneous rock, probably in the form of thin, discontinuous basalt flows interbedded with basin fill (Figures 6 and 7; Section 2.2).

Alluvial fan deposits of four relative ages, terrace deposits, sheet sand and sand dunes, and contemporary stream channel deposits comprise the surficial basin-fill material (Table 5, Figures 8 through 15; Section 4.4). Throughout much of the Valley, younger fan units (A5y, A5yf) form a relatively thin veneer (less than five feet; 1.5 m) with underlying older (A5o), intermediate (A5i) and intermediate-younger (A5iy) units locally

exposed (Drawing 2). A5i and A5iy units are present at shallow depths throughout the Valley.

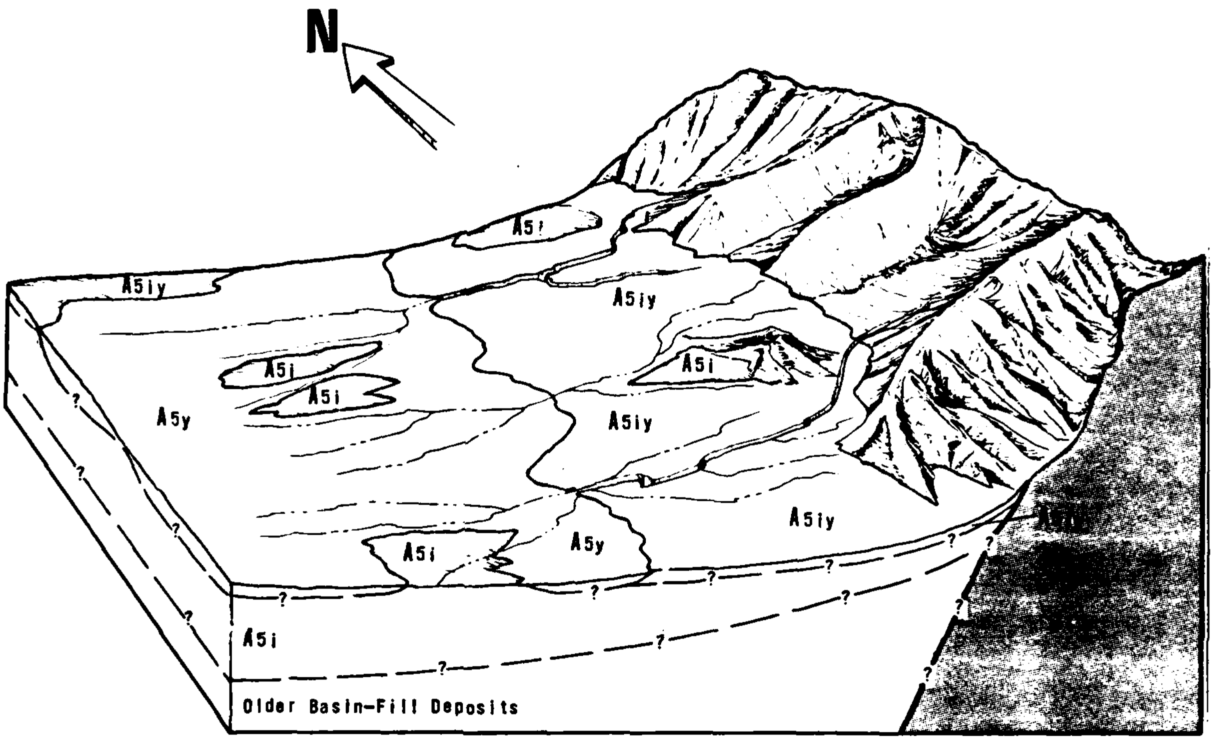
Where exposed, the A5oc, A5i, and A5iy fan units are topographically higher and occur principally adjacent to the mountain fronts. Here, drainages are deeply incised,exposing the proximal parts of older (Gila Mountains), intermediate and intermediate-younger (Gila and Copper Mountains) units. These are in turn buried at their distal portions where younger fan material deposited from these drainages spreads over the surface (Figures 4 and 5). Alluvial fans originating from metamorphic sources tend to contain larger, more angular, and less weathered boulders, cobbles, and gravels than those emanating from intrusive igneous sources; the result of chemical and mechanical weathering rates which are much higher in intrusive igneous than metamorphic rocks.

2.1.4 HYDROLOGY

2.1.4.1 Surface Hydrology

Surface drainage within the Valley is limited to ephemeral streams. The primary through-flowing drainage in the Valley is the north-northwest trending Coyote Wash (Drawing 2). In general, channels in the central Valley are transitory and less than two feet deep (0.6 m), whereas channels near the mountain front in older (A5oc) alluvial fan units are incised up to 50 feet (15 m) deep. Stream densities range from less than one drainage per nm (2km) in the Central Valley to over 25 per nm (2km) along the mountain fronts (Section 2.4.4).

No evidence of recent extensive debris flows was observed in Lechuguilla Desert and in fact, it is reported that no known



Schematic block diagram depicting the general configuration and relationships of basin-fill deposits along the western Copper and eastern Gila Mountains. Intermediate-younger alluvial fans (A5iy) bury intermediate alluvial fans (A5i) adjacent to the mountain front. Present drainages entrench both A5i and A5iy alluvial fans. Younger alluvial fans (A5y) form where drainages emerge from entrenched channels and partially bury existing alluvial fan deposits.

BLOCK DIAGRAM OF BASIN-FILL RELATIONSHIPS ALONG THE WESTERN COPPER AND EASTERN GILA MOUNTAINS LECHUGUILLA DESERT, ARIZONA	
MX SITING INVESTIGATION DEPARTMENT OF THE AIR FORCE - SAMSO	FIGURE 4
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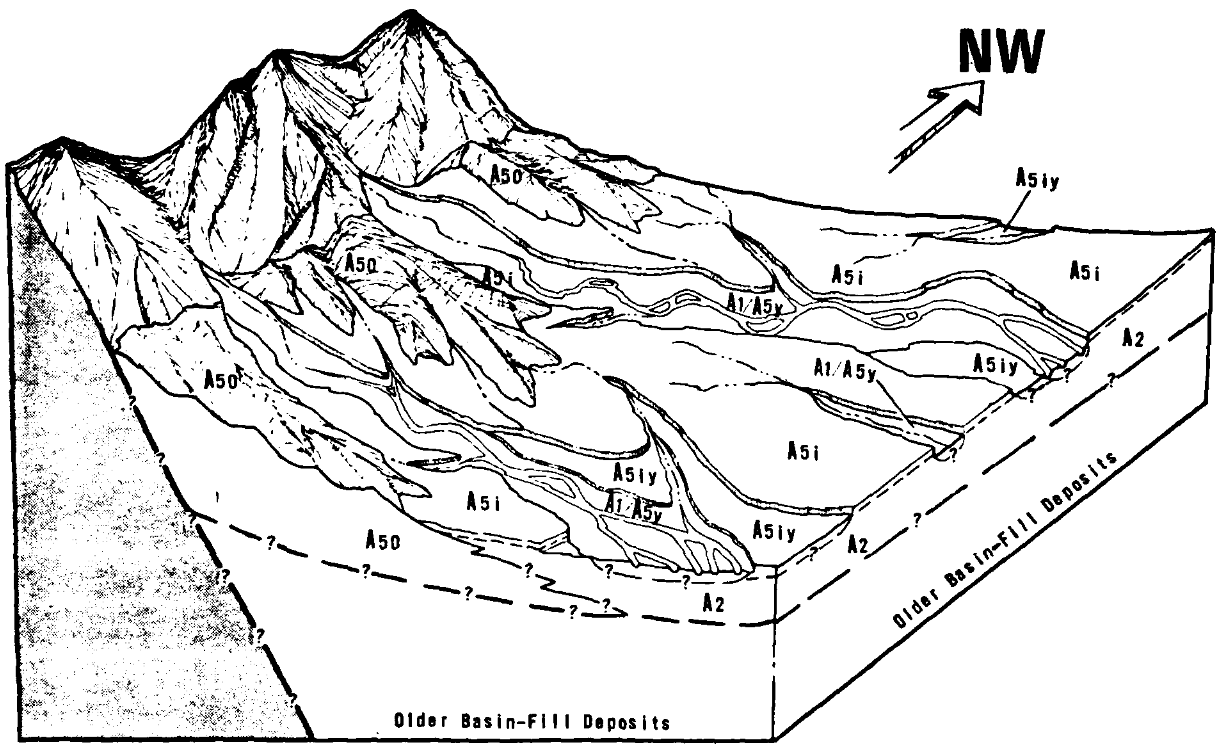

Schematic block diagram depicting the general configuration and relationships of basin-fill deposits along the northern Gila Mountains in northwestern Lechuguilla Desert. Highly dissected older alluvial fans (A5o) are exposed only near the Gila Mountain front. Both older alluvial fans (A5o) and terrace deposits (A2) are partially buried basinward by intermediate alluvial fans (A5i). Stream drainages were entrenched following deposition of A5i fans forming broad, steep-walled channels floored by intermediate-younger alluvial fan deposits (A5iy). Continued entrenchment and stream transport has resulted in formation of mixed braided stream channel and younger alluvial fan deposits (A1/A5y) within larger channels.

BLOCK DIAGRAM OF BASIN-FILL RELATIONSHIPS ALONG THE NORTHERN GILA MOUNTAINS LECHUGUILLA DESERT, ARIZONA

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FIGURE 5

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debris flows in Yuma Proving Ground/Luke-Williams Bombing and Gunnery Range have occurred in historic times (H. F. Barnett, oral communication, 1975). However, where steep slopes, fractured and possibly loose rock are present, high intensity or long duration rainfall could induce debris flows. These conditions prevail along the steep mountain fronts surrounding Lechuguilla Desert.

In Lechuguilla Desert, the highest potential for flooding is in stream channels from the mountain front to the point in those channels where transported materials spread out to form coalescing younger alluvial fans (A5y).

Central Valley younger basin-fill units (A5y) and sheet sand (A3s) have generally lower flooding potential but are subject to sheet and overbank flooding during severe storms. Flooding, however, even during a severe storm, is limited to low energy flow on the gentle surface slope and is quickly dissipated on these central Valley alluvial units.

Surficial basin-fill units least susceptible to flooding are sand dunes (A3d) due to their high permeability and relief; and older, intermediate and intermediate-younger alluvial fans (A5oc, A5i and A5iyf) whose surfaces are exposed towards the center of the Valley, and are topographically higher than surrounding younger fans remain above most flooding other than that caused by direct rainfall. Along the mountain fronts, the more highly dissected older, intermediate, and intermediate-younger fan surfaces are not usually subjected to surface flooding as flood water is

generally channelized. Occasional overbank flooding occurs during very intense prolonged rainfall, as evidenced by recently disturbed pavement on an intermediate level fan in northwest Lechuguilla Desert, and on younger alluvial fans where man made structures interfere with natural drainages such as occurred during Tropical Storm Doreen in mid-August of 1977 (Section 4.7.1.5).

2.1.4.2 Groundwater Hydrology

Groundwater was encountered in four borings and substantiated by a scale shift on the downhole geophysical logs in Lechuguilla Desert:

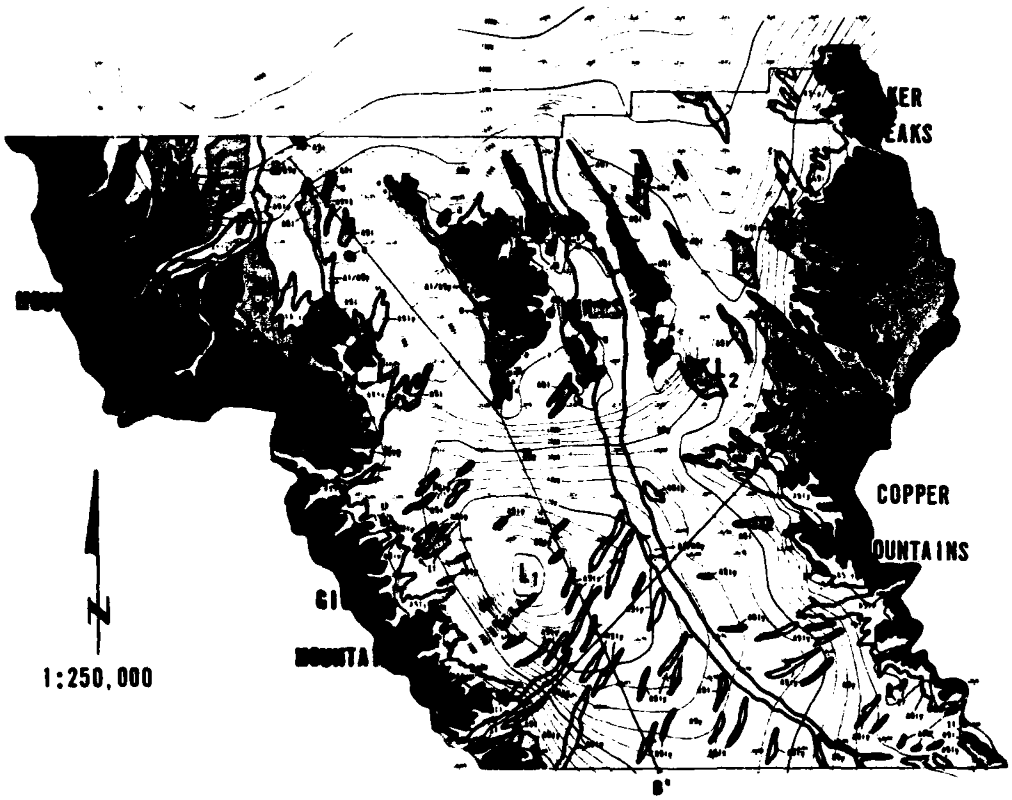
Boring	Location	Surface Elevation	Depth to Groundwater	Groundwater Elevation
LD-B-1	East Central	870' (265 m)	125' (38 m)	745' (227 m)
LD-C-2	Northwest	490' (149 m)	153' (47 m)	337' (103 m)
LD-C-5	Southeast	870' (265 m)	248' (76 m)	622' (190 m)
LD-D-1	West Central	780' (238 m)	366' (112 m)	414' (126 m)

2.2 BASIN SHAPE AND SEISMIC VELOCITY PROFILE

The interpreted shape of the crystalline basement within Lechuguilla Desert is based primarily on measurements of the gravitational field, with the depth calculations being constrained by boring and seismic refraction data (Figures 6 and 7). Figure 6 includes a simplified geologic map with a generalized depth to basement overlay, and Figure 7 presents two generalized composite cross-sections of Lechuguilla Desert. A more detailed map is shown as Drawing A-2.

South of the Wellton Hills, the Lechuguilla Desert basin is a closed feature, with the depth to basement increasing in all directions toward the location marked L_1 on Figure 6 and Drawing A-3. The basin is bounded to the west and east by relatively steep NW-SE trending flanks. A steep linear gradient which trends E-W separates the Basin from the Wellton Hills on the north. Steep linear gravity gradients are probably indicative of fault controlled Basin and Range structure. The axis of the basin trends approximately NW-SE. The maximum depth of the basin is about 7500 feet (2290m) at latitude 32° 29′; longitude 114° 08′. The depth decreases to about 3000 feet (915m) at the southern end of the study area.

The interpreted depth and apparent dip of the basement surface beneath seismic lines LD-DS-1 and LD-DS-2 agrees with the gravity interpretation within 20 percent. The correlation between the two sets of data is shown on the gravity and magnetic profiles G/MP/-AA′ and G/MP-BB′ (Figures A-3 and A-4) which coincide with, and extend beyond the positions of the seismic lines. Apparent



EXPLANATION

SURFICIAL BASIN-FILL UNITS

A1, A2, A3 and A5y - stream channel, terrace, eolian and younger fan deposits

A5iy - intermediate-younger fan deposits

A5i - intermediate fan deposits

A5o - older fan deposits

ROCK UNITS

S - Sedimentary

Ii - Igneous; intrusive

M - Metamorphic

Fault, approximately located, dotted where concealed.

NOTE: See Drawing 1 for locations of activities and Drawing 2 for complete explanation of units and symbols.

SYMBOLS

A ——— A' Composite Section, See Figure 7.

— 1000 — Estimated depth to basement rock, contour interval = 500 feet.

H_1 Relative Basement High

L_1 Relative Basement Low

NOTE: Basement depths and configuration based on gravity interpretation.

GENERALIZED GEOLOGIC MAP AND ESTIMATED DEPTH TO BASEMENT ROCK LECHUGUILLA DESERT, ARIZONA

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FIGURE 6

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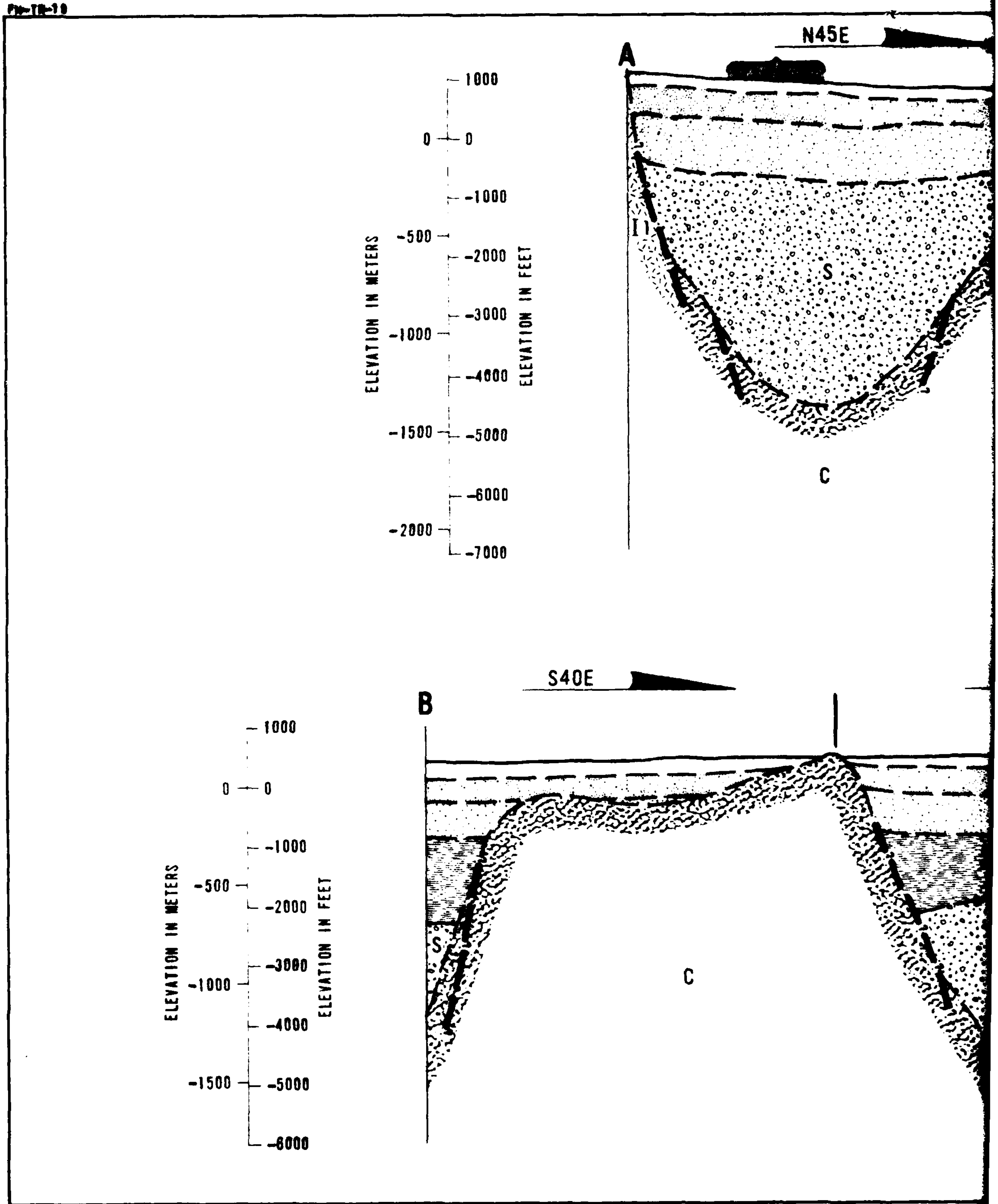

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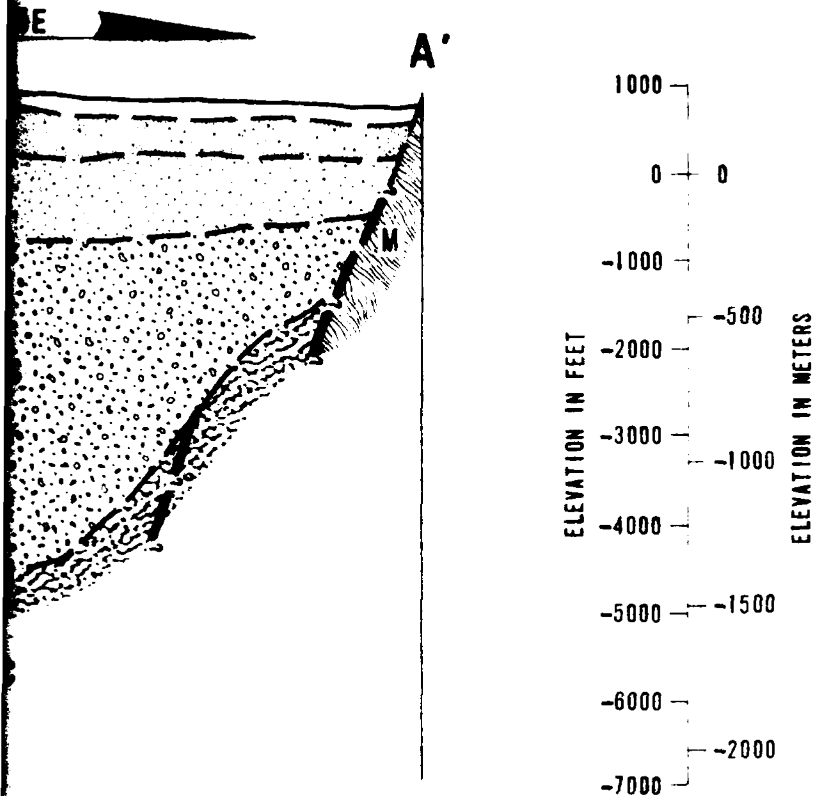

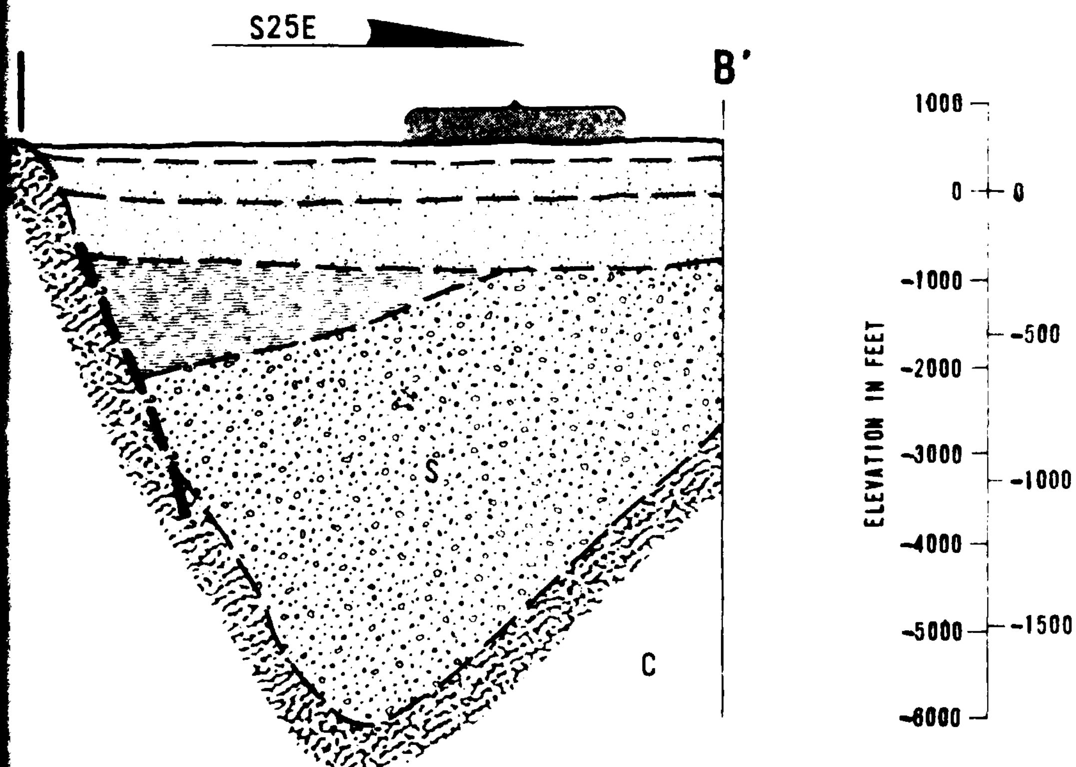

EXPLA

SURFICIAL BASIN F
deposits; average
(800–1100 mps).

LACUSTRINE/MARINE
average seismic v

OLDER BASIN FILL;
material; average
(2150–3350 mps).

OLDER BASIN FILL;
and possibly mari
velocity 9700 fps

SEDIMENTARY ROCK
INTRUSIVE IGNEOUS
METAMORPHIC ROCK
IGNEOUS/METAMORPH

Geologic Contact;

Fault; Geophysica

Zone of Aeromagne
igneous rock; ex

NOTES:
(1) Cross sect
(2) Basement
(3) Seismic v
seismic r

HORIZONTA
STATUTE MILES 0 1
KILOMETERS 0 1 2

Vertical Exaggerati

2

EXPLANATION

SURFICIAL BASIN FILL; Alluvial fans and playa lacustrine deposits; average seismic velocity 2650–3400 fps (800–1100 mps).

LACUSTRINE/MARINE; Older material not exposed at the surface; average seismic velocity 3500–5000 fps (1050–1800 mps).

OLDER BASIN FILL; Well indurated alluvial and colluvial material; average seismic velocity 6900–7500 fps (2150–3350 mps).

OLDER BASIN FILL; Very well indurated alluvial and possibly marine deposits; average seismic velocity 9700 fps (3050 mps).

S, II, M, C

SEDIMENTARY ROCK (S)

INTRUSIVE IGNEOUS ROCK (II)

METAMORPHIC ROCK (M)

IGNEOUS/METAMORPHIC ROCK COMPLEX (C)

Geologic Contact; dashed where approximate.

? ?

Fault; Geophysical interpretation.

Zone of Aeromagnetic Anomaly may indicate shallow igneous rock; exact configuration unkown.

NOTES:

(1) Cross section locations shown on Figure 6.
(2) Basement profiles from Drawing A-3.
(3) Seismic velocities determined from deep seismic refraction lines.

ELEVATION IN FEET: 1000, 0, -1000, -2000, -3000, -4000, -5000, -6000

ELEVATION IN METERS: 0, -500, -1000, -1500

HORIZONTAL SCALE

STATUTE MILES 0 1 2 3

KILOMETERS 0 1 2 3 4

Vertical Exaggeration: 5X

GENERALIZED COMPOSITE CROSS SECTIONS
LECHUGUILLA DESERT, ARIZONA

MX SITING INVESTIGATION
DEPARTMENT OF THE AIR FORCE - SAMSO

FIGURE 7

FUGRO NATIONAL, INC.

2

3

steeply dipping flanks of the Wellton Hills and the Gila Mountains, as shown on the profiles, are prominent features, suggesting high angle (greater than 45°) fault scarps of considerable vertical displacement (as much as 3000 feet, 915 m).

A general compressional wave velocity profile for the basin compiled from seismic lines LD-DS-1 (Figure A-1) and LD-DS-2 (Figure A-2) is listed below:

Velocity Zone	Compressional Wave Velocity (feet/second; m/sec)	Maximum Thickness (feet; m)
1	3000; 915	300; 91
2	3900; 1190	600; 182
3	7300; 2226	1400; 427
4	9700; 2957	1200; 366
5	14,000; 4268	4000; 1220
6	16,000; 4878	Undetermined

Velocity zone 1 represents alluvial fan deposits and possible playa/lacustrine materials underlying the unconsolidated, thin younger alluvial fan unit (A5y, A5yf). Velocity zone 2 seems to represent older, playa/lacustrine deposits overlying Velocity zone 3, which may be the well-indurated alluvial fan/fanglomerates, the youngest of which (A5oc) are exposed around the basin periphery. Velocity zones 4 and 5 could be representative of the very highly indurated older fanglomerates and sedimentary bedrock. They may also represent intrusive igneous material. Velocity zone 6 is interpreted to represent crystalline basement rocks. The velocities indicated and their relationships

to specific lithologic units must be evaluated carefully. Highly weathered zones within each unit can have substantially lower velocities as illustrated by LD-S-4 where the nominal 7500 feet per second (2290 m/s) material was confirmed as highly weathered crystalline basement rock in adjacent boring LD-B-1.

2.3 BASIN-FILL UNITS

2.3.1 EXPOSED GEOLOGIC UNITS

Surficial basin-fill deposits cover 125 nm^2 (435 km^2) or 76 percent of the total 164 nm^2 (570 km^2) area of Lechuguilla Desert (Drawing 2). The most extensive units in terms of surface exposure, are the younger alluvial fans (A5y, A5yf) which cover 84 nm^2 (288 km^2) or 51 percent of the Valley area. Older alluvial fans (A5oc), covering 3 nm^2 (10 km^2); intermediate alluvial fans (A5i, A5if), covering 10 nm^2 (34 km^2); and intermediate-younger alluvial fans (A5iy, A5iyf), covering 14 nm^2 (48 km^2), crop out along the basin periphery adjacent to mountain fronts. Isolated remnants of A5iy are also exposed throughout the Valley, particularly in the central Valley. Intermediate fan deposits underlie the entire Valley at depths generally less than five feet (1.5 m) and represent the most volumetrically extensive deposit within the construction zone (30 feet; 9m) in Lechuguilla Desert (section 4.4.2). Block diagrams illustrating basin-fill deposit configurations are shown schematically on Figures 4 and 5 of Section 2.1.3.

Other surficial units in order of decreasing surface exposure are: eolian sand (A3d, A3s; Section 4.4.4); stream channel deposits (A1; Section 4.4.5); terrace deposits (A2; Section 4.4.3); and colluvial deposits (Section 4.4.6). Small isolated and stabilized dunes occur locally in the central and southeastern Valley. Stream channel deposits occur at many locations in the Valley, but due to scale limitations are generally not illustrated on the Geologic Map (Drawing 2). Coyote Wash and unnamed channels

in the northwest corner of the Valley are the only significant ephemeral streams. Colluvium occurs intermittently at the base of steep slopes in the Gila and Copper Mountains. In general, the maximum extent of a single colluvial deposit is less than 0.1 nm^2 (0.3 km^2) with estimated maximum thickness of 30 to 50 feet (9 to 15 m).

2.3.2 SUBSURFACE DEPOSITS

2.3.2.1 Distribution

The subsurface deposits of Lechuguilla Desert underlying the relatively thin veneer of younger and intermediate alluvial fan units are older basin-fill deposits consisting of predominantly silty and clayey sands. The upper 300 feet (91 m) of these deposits are illustrated by four soil profiles presented on Drawing 3. Percentage of fines within these sand deposits generally increases toward the central portion of the Valley. Sand deposits underlying the younger alluvial fans (A5y and A5yf) typically have 15 to 45 percent fines.

Silty and clayey sand deposits underlying the finer grained intermediate and younger alluvial fans (A5yf, A5ic) generally contain less than ten percent gravel and no cobbles or boulders. Toward the mountains, the percentage of gravel increases and cobbles and boulders are encountered. Based on geological field observations and limited trench excavations, the percentage of gravel, cobbles, and boulders is estimated to be generally less than 30 near the mountain fronts. However, in the northwestern corner of the Valley where the source rock is metamorphic, the percentage often exceeds 50 within three miles (5 km) of the

source rock. The largest boulder observed in a trench was 24 inches (60 cm) encountered at trench LD-T-22 in the northwestern portion of the Valley (Section 4.4.6).

Fine grained units of predominantly clay deposits were not encountered at the surface of the Valley, although they are present in the subsurface. In the upper 50 feet (15 m), those deposits are less than 20 feet (6 m) thick and generally encountered at the northern and eastern portions of the Valley as shallow as three feet (1 m) below ground surface.

The deep fine grained deposits were encountered in several borings throughout the Valley; clear correlations cannot be made between borings. The thickest fine-grained deposit was encountered in the southern half of the Valley at boring LD-D-1. This fine grained deposit begins at 86 feet (26 m) below ground surface at elevation 689 feet (210 m) and continues to the full depth (800 feet; 244 m) of the boring, interrupted three times by silty sand deposits. In LD-C-2, located in the northwestern portion of the Valley, the fine grained deposit begins at 41 feet (13 m) below ground surface at elevation 449 feet (137 m) and is interrupted twice by silty sand deposits and continues to the full depth of the boring (301 feet; 92 m).

In the north central portion of the Valley a relatively extensive fine grained deposit was encountered at borings LD-B-16 and LD-C-6 near elevation 485 feet (148 m). At LD-B-16, the fine grained deposit begins at eight feet (2 m) below ground surface and continues practically uninterrupted to a depth of

about 94 feet (29 m), where it is underlain by silty sand and sandy silt. However, at LD-C-6 the fine grained deposit is only about 15 feet (5 m) thick, beginning at a depth of about 73 feet (22 m) below ground surface.

Other isolated areas of relatively thin fine grained deposits were encountered at borings LD-A-1, LD-A-3, LD-A-5, LD-B-2, LD-B-6, LD-B-14, LD-B-15, LD-B-17, LD-C-3, LD-C-4, LD-C-5, and LD-D-2. Soil Profiles (Drawing 3; in pocket), Boring and Trench Logs (Appendix C) and Sections 5.3.2.1 and 5.3.3.1 show further details.

2.3.2.2 Physical and Engineering Properties

Physical and engineering properties of subsurface deposits are discussed in detail in Sections 3.0, 4.0, and 5.0. Typical engineering properties of the coarse and fine grained deposits are summarized in Table 1.

2.3.2.3 Chemical Properties

The chemical properties, in particular the water soluble sulfate content, are discussed in Section 5.3.2.9. Based on very limited tests, some soils would cause severe sulfate attack and require high sulfate resistant concrete (type V cement).

ENGINEERING PROPERTIES	UPPER 50 FEET (15.2 M)		50 TO 300 FEET (15.7 TO 91.4 M)	
	SILTY SANDS AND CLAYEY SANDS	SILTS AND CLAYS	SILTY SANDS AND CLAYEY SANDS	SILTS AND CLAYS
Dry Unit Weight	116 pcf (1858 kg/m^3)	106 pcf (1698 kg/m^3)	117 pcf (1874 kg/m^3)	106 pcf (1698 kg/m^3)
Moisture Content	2.7%	7.7%	2.9%	15.3%
Shear Strength Friction Range	36° - 39°	11° - 20°	36° - 39°	11° - 20°
Cohesion	0.3-1.5 ksf (14-72 kN/m^2)	3 ksf (144 kN/m^2)	0.3-1.5 ksf (14-72 kN/m^2)	7 ksf (335 kN/m^2)
Maximum Dry Density (ASTM D-1557-70)	133 pcf (2130 kg/m^3)	129 pcf (2066 kg/m^3)	--	--
Optimum Moisture Content	8.0%	8.6%	--	--
California Bearing Ratio (CBR) at 90% of Maximum Density	15	--	--	--
Compressional Wave Velocity	2450 ft/sec (747 m/s)	3100 ft/sec (945 m/s)	5150 ft/sec (1570 m/s)	5050 ft/sec (1539 m/s)
Shear Wave Velocity	1230 ft/sec (375 m/s)	1240 ft/sec (378 m/s)	2700 ft/sec (823 m/s)	1600 ft/sec (488 m/s)
Young's Modulus	14,500 ksf (694,300 kN/m^2)	14,200 ksf (680,200 kN/m^2)	69,400 ksf (3,320,800 kN/m^2)	24,300 ksf (1,164,300 kN/m^2)
Bulk Modulus	14,400 ksf (686,800 kN/m^2)	24,900 ksf (1,190,400 kN/m^2)	61,000 ksf (2,920,400 kN/m^2)	72,700 ksf (3,478,300 kN/m^2)
Shear Modulus	5400 ksf (260,700 kN/m^2)	5100 ksf (242,100 kN/m^2)	26,500 ksf (1,267,000 kN/m^2)	8400 ksf (403,100 kN/m^2)
Poisson's Ratio	0.33	0.41	0.31	0.44

TYPICAL ENGINEERING PROPERTIES OF SUBSURFACE DEPOSITS FROM ZERO TO 300 FEET (90 m) LECHUGUILLA DESERT, ARIZONA

MX SITING INVESTIGATION
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TABLE 1

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2.4 CONSTRUCTION CONSIDERATIONS

2.4.1 EXCAVATABILITY

Most excavations extending to depths of 20 to 25 feet (6 to 8 m) and located more than a mile (2 km) from the mountain fronts or isolated rock outcrops would be in slightly to moderately cemented silty and clayey sands. It can be expected that in these areas there will be practically no boulders or cobbles and the percentage of gravel will generally be less than 10 percent. The seismic compressional wave velocities at these depths do not generally exceed 3000 feet per second (915 m/sec). Based on these conditions, it is expected that excavations can be made with heavy duty construction equipment. It is anticipated that all materials will be rippable and that difficult ripping (i.e., a single shank ripper on a Caterpillar D-9 dozer) would be limited to localized, highly cemented zones. Such zones were not encountered more than a mile (2 km) from the mountain fronts, except the intermediate and older alluvial fan deposits (A5i, A5oc) in the northwestern portion of the Valley where they extend to approximately three miles (5 km) from the mountain fronts.

The soils in the upper 25 feet (8 m) generally contain 15 to 40 percent fines (silt and clay), have low moisture contents, are variably cemented, and generally have high cohesive strength. Light equipment, such as a Caterpillar D-6 or D-7 dozer, may have some difficulty excavating below about five feet (2 m) and progress would be slow.

Within a mile (2 km) of the mountain fronts, excavation will be more difficult primarily due to a higher percentage of gravels, cobbles, and boulders. If excavations were to extend to within a few hundred feet (meters) of the mountain front, the typical material to be excavated would be a sandy gravel, with various percentages of cobbles and boulders. The percentage of cobbles and boulders could attain, but rarely be greater than, 50 percent.

The 23 exploration trenches excavated in Lechuguilla Desert provide a practical means to evaluate the excavatability of the subsoils. In 17 trenches, a Caterpillar 225 backhoe was able to excavate to a depth of 20 feet (6 m) even though the excavated soils were moderately cemented. However, in trenches LD-T-5, LD-T-6, LD-T-17, LD-T-19, LD-T-21, LD-T-22 excavations to 20 feet (6 m) were not possible. In trenches LD-T-5, LD-T-17, and LD-T-19 located in the north central Valley within a few hundred feet (meters) of isolated rock outcrops, rock was encountered at depths ranging from 13 to 17 feet (4 to 5 m) and deeper excavation was not possible. In the intermediate alluvial fan deposits located within two miles (3 km) of the mountain front in the northwestern portion of the Valley, two trenches were excavated to depths less than 20 feet (6 m). In LD-T-21 (northeast portion of the Valley) a strongly cemented older alluvial fan deposit was encountered at a depth of 10 feet (3 m) and excavation was stopped at about 12 feet (4 m) due to very slow progress. In LD-T-22 (northwest portion of the Valley) large boulders, with a maximum size of 24 inches (60 cm) were encountered at a depth as

as shallow as two feet Z(60 cm) and excavation deeper than 15 feet (5 m) was not possible due to increasing cementation, size and amount of boulders. In the southeastern portion of the Valley, within a few hundred feet (meters) of the mountain front in the intermediate alluvial fan units (A5i), trench LD-T-6 was terminated at a depth of about eight feet (2 m) where an indurated quartz monzonite rock was encountered. The remaining trenches throughout the Valley were excavated to the desired depth of about 20 feet (6 m) with no major difficulty.

The difficult excavation conditions encountered in some trenches are local conditions near the mountain fronts or isolated outcrops. Where such conditions exist, difficult ripping can be expected and excavations will proceed at a slow rate. Should excavations extend into areas where rock units are exposed at the surface or are encountered at shallow depths, blasting may be required.

Compressional wave velocities obtained from shallow seismic refraction lines and downhole velocity surveys in the upper 25 feet (8 m) were generally less than 3000 feet per second (915 m/sec) indicating that all these soils are rippable. Most rippability charts show th t soil deposits with compressional wave velocities less than 6000 or 7000 feet per second (1830 to 2135 m/sec) can be ripped.

With the exception of a few borings near the mountain fronts and isolated rock outcrops, all borings generally encountered smooth drilling in the upper 25 feet (8 m). Penetration of the hollow

stem auger at a normal rate generally indicates that the deposit should be rippable by conventional heavy duty construction equipment.

2.4.2 SLOPE STABILITY

Excavations to construct either MX system design concept will have a minimum width of approximately 16 feet (5 m) and a depth of about 20 feet (6 m). Because of terrain conditions, the depth of buried trench excavations could increase to 25 or 30 feet (8 or 9 m) in local areas. The shape of excavated slopes will depend on three primary factors:

a. The composition and shear strength of the materials being excavated.

b. The construction method being used and the effect of the method on stability.

c. The Occupational Safety and Health Administration (OSHA) requirements regarding safety of personnel working in excavations.

Because of the interrelationship of these three factors and because of the limited subsurface data at present, it is not possible to provide specific recommendations regarding slope angles of unshored excavations. Some comments can be made about the shear strength of soils and what typical slope angles would be feasible, disregarding factors "b" and "c".

Most of the soils to be excavated have 15 to 40 percent fines to provide some cohesive strength at normal in situ moisture conditions. In addition, many of the soils are slightly to

moderately cemented except the younger alluvial fan deposits (A5y, A5yf) which are generally not cemented and are relatively loose in the upper one to three feet (30 cm to 1 m); this unit is generally not more than five feet (2 m) thick. Based on these typical conditions, stable unshored excavations could be made if the following conditions are met:

a. All loose soils in the upper one to three feet (30 cm to 1 m) are removed, laid back to 3:1 (horizontal:vertical) slopes or flatter, or recompacted within the working area adjacent to the excavation.

b. Portions of all slopes within four to eight feet (1 to 2 m) of the existing surface are cut back to no steeper than 1:1.

c. Below depths of four to eight feet (1 to 2 m), vertical cuts can be made.

Near the mountain fronts, it is expected that vertical cuts in gravelly sand zones below depths of four to eight feet (1 to 2 m) will be possible, since these materials are also cemented. However, subsurface zones and lenses of poorly or non-cemented gravels such as buried stream channel deposits may be encountered. In such materials, vertical cuts should be grossly stable, but ravelling of coarse materials could be expected, particularly if excavations are left open for more than a few days.

If excavations are to extend to within several hundred feet (meters) of mountain fronts and the materials typically consist of sandy gravels with cobbles and boulders, it will be necessary to cut slopes back at 3/4:1 or 1:1 to provide adequate stability.

Even when cut back, there is the danger of cobbles or boulders being loosened during excavation and becoming dislodged during construction.

Photographs of some of the trench excavations are included in Appendix C (Figures C-64 through C-68).

2.4.3 MATERIAL CHARACTERISTICS

For MX construction, it is assumed that the protective structures will be founded on soils at a depth of about 20 feet (6 m) below existing grade. At this depth, the dense, cemented silty sand and clayey sand will provide excellent foundation support for the structures. For a cast-in-place buried trench system, it should be possible to shape the bottom of the trench so that concrete can be placed directly against the surface. Shaping will be more difficult near the mountain fronts due to the presence of gravel and some cobbles and boulders. The soils generally have low compressibility and settlements are expected to be negligible if foundations are properly constructed on undisturbed material.

In localized areas, clays may be encountered at foundation level. At their existing low moisture content, these soils will also provide suitable foundation support. These materials are generally expansive and some swelling could occur if they were to become saturated. However, proper compaction around the protective structure and good surface drainage should minimize the probability of foundation soils becoming saturated.

Considering the relatively deep ground water conditions in Lechuguilla Desert, saturation of the foundation soils due to a rising ground water table is unlikely.

Most of the materials to be excavated will be suitable as backfill material for protective structures. Some clays will be encountered at the northern and eastern ends of the Valley and in other local areas. These materials will be the most difficult to compact because of the problems of proper moisture conditioning and because of the compaction energy needed to obtain the required density. The silty and clayey sands will be easier to process and to compact and because there are sufficient volumes of these materials, it will probably be more economical to use them, provided haul distances are reasonable.

The sand-gravel mixtures near the mountain fronts will be excellent material for backfilling. The only potential problem will be the presence of large cobbles or boulders which can be expected within approximately one mile (2 km) of the mountain front. It is expected that boulders can be removed at the time of excavation and that cobbles can be used in the backfill provided they are not placed within a few feet of the protective structure. When excavated natural soils are compacted some shrinkage is expected to occur. At 92 percent relative compaction (ASTM D-1557-70), the average percent shrinkage, with respect to the volume of natural soils excavated, should be approximately five percent.

Because of the very low moisture content of the in situ soils, additional water will be required for proper compaction. In silty and clayey sands, water will have to be added to increase the moisture content (Table 1) to about five to seven percent to obtain 90 percent relative compaction.

One problem to be considered in construction planning is dust created by excavation equipment and by all equipment travelling on temporary roads. Road dust can be minimized by spraying the final surface with a road oil or some other dust retardation material, or by constant watering. To reduce dust during excavation, water spraying will be required of the materials being excavated.

Primary and service roads will be constructed if Lechuguilla Desert is selected as a deployment site. For primary and possibly service roads, a suitable base course will be required. Most of the soils in the upper 20 feet (6 m) are too fine grained to be used as a base course. Only the materials within one-half mile (1 km) or less of the mountain fronts are likely to be coarse enough and these materials may have too high a percentage of fines to meet normal gradation specifications.

In addition to a road network, working pads will have to be provided adjacent to excavations to provide access for construction equipment. The preparation of such working areas could be a significant cost item because of the presence of loose materials in the upper one to three feet (30 cm to 1 m). Either the loose materials will have to be removed to expose a suitable,

working surface or they will have to be removed, brought back in layers, moisture conditioned, and recompacted.

Preliminary evaluation of the basin-fill deposits and exposed rock in Lechuguilla Desert indicate these materials may not be usable as aggregate in good quality concrete. Pit- and crusher-run gravels would consist of metamorphics, which often break down easily and intrusive igneous rocks which are often friable. The sands may be suitable if they are washed to remove most of the fines. A more comprehensive materials resources study is currently underway and results will be available in early FY 78.

2.4.4 HAZARDS OR DIFFICULT CONSTRUCTION AREAS

Areas which are known to be or are suspected of being capable of causing construction or facility maintenance problems within Lechuguilla Desert were investigated; a brief summation, and the pertinent report sections are delineated below.

Except for Coyote Wash, primary drainage channels and abnormally rough terrain occur only adjacent to the Baker Peaks, Copper and Gila Mountains, generally within 1000 feet (305 m) of exposed rock on steep upper slopes of older, intermediate and intermediate younger (A5o, A5i, A5iy) alluvial fans (Drawing 2). Channels within older alluvial fan units (A5o) in the northwestern portion of the Valley are incised up to approximately 55 feet (17 m) and range up to 230 feet (70 m) in width but have generally less than 15 feet (4 m) incision and 100 feet (30 m) width throughout the remainder of the peripheral Valley (Sections 2.1.2, 4.3; Table 5, Microrelief Profiles Appendix B). Terrain conditions will affect alignment of roads and trenches.

Very limited areas of loose sand are contained in thin sheets and isolated dunes within the Valley. These sands are generally loose and estimated to be not more than ten feet (3 m) thick. Excavation slopes will likely require special consideration to facilitate stability.

Landslide and slump areas were not observed within the suitable portion of the Valley (areas of less than ten percent slope) and are not expected to affect construction and operations.

Surface rupture, due to active faulting within the suitable siting area was not observed and is not expected to be a potential hazard within the Valley.

Lechuguilla Desert in general has a very low flooding potential. Runoff will be mostly channelized or occur as sheet flow over pavemented fan surfaces. Debris flow would likely occur only within channels at the proximal ends of alluvial fans adjacent to the mountain fronts. No evidence of historic debris flows other than local overbank deposits was observed, therefore the likelihood of such occurrences is low. Man-made obstructions across existing drainages or fan surfaces will redirect runoff and depending on local gradients, new erosion/deposition conditions will result (Sections 2.1.4.1, 4.7.1.6; Drawing 2, Microrelief Profiles, Appendix B). Stream densities range from 0 to 25 drainages per nautical mile (2 km), generally increasing with proximity to mountain fronts (A5oc, A5i, A5ic), however, greater than 50 percent of the alluvial deposits (A5y, A5yf) have stream densities from 0 to 6. Depth of incision decreases with distance

from the mountains to generally less than one foot (30 cm) in the central Valley (Section 2.1.4.1). Ground or perched water was not encountered or recorded at depths less than 125 feet (38 m) and is not expected in construction excavations (Sections 2.1.4.2, 4.7.2).

The observed occurrences of near-surface hard rock indicate that this condition may be present in relatively broad local areas mainly in northern portions of the Valley adjacent to Wellton Hills and Baker Peaks. This could result in local excavation difficulties (Section 2.4.1, 4.4.4.1; Drawings 1 and 2).

Boulders exceeding six feet (2 m) in diameter are extremely rare in Lechuguilla Desert. They were observed only in the colluvial deposits and drainages emerging from steep rock-floored canyons immediately adjacent to metamorphic portions of the Gila and Copper Mountains ((Sections 2.3.1, 4.4.2, 4.4.6; Drawing 2).

2.5 METHODOLOGY EVALUATION

As with any construction project, certain specific types of geotechnical data are, and will be, required to site, design, construct and monitor performance of the required facilities. The initiator of the project wants enough data to see that these things are done (to his desired degree of reliability or confidence) such that each element will prove successful. He would like to do this in the least amount of time for the least amount of money. This dictates a technically effective, schedule effective, and cost effective program,. The ultimate objective of any methodology evaluation should be to define such a program. Results of more detailed analyses to meet this objective will be presented in a report to be completed by the end of March 1978.

This sections presents a summary evaluation of the engineering geology, soils engineering, and geophysical methodologies (techniques) utilized for the Lechuguilla Desert investigation. It represents judgements as to the effectiveness of each technique relative to satisfaction of the original objectives, and suggests applications for future Validation investigations. The tabulated summary information which follows includes:

1. The technique and its scope of application in Lechuguilla Desert;
2. Objectives of each technique;
3. Effectiveness relative to the original objectives;
4. General comments as appropriate; and
5. The applicability of each technique to Validation studies.

GEOPHYSICAL METHODOLOGY EVALUATION

METHOD/QUANTITY	OBJECTIVE(S)	EFFECTIVENESS	COMMENTS	APPLICATION TO VALIDATION
Gravity/241 Ground Stations	Basin shape; depth estimates to crystalline basement rock	Highly suited to alluvial filled or semi-closed basins having a significant, relatively abrupt density contrast with depth; accuracies commonly within 20%	Highly interpretive; slow progress in difficult terrain; although expensive, a helicopter would avoid ground disturbance	Useful for V&H modeling of basin shape in "basin and range" type provinces
Aeromagnetics/ 250 nm^2 (402 km^2)	Locate possible shallow rock; estimate basin depth; approximate deep basin structure	Suited to areas with past igneous activity; including indications of volcanic flows; difficult to assess without specific post-interpretative drilling program	Data acquisition rapid; processing slow; should be accomplished very early in program; very highly interpretive	Use in areas containing known or suspected shallow igneous rock, especially volcanic flows in basin fill
Long Range "Deep" Seismic Refraction/ 2 lines total 12 nm (19 km)	Obtain gross deep layer velocity, structure and estimate basement depth	Good results where materials at depth propogate waves at higher velocity than overlying materials and where shallow materials are conducive to initial energy propogation; accuracies generally within 20%	Requires relatively large explosive charges and shot hole drilling; extremely useful to assist in gravity interpretation	Useful for V&H modeling of basin shape and seismic velocity profile and layer depths/thicknesses
Short Range "Shallow" Seismic Refraction/15 lines (20,400'; 6220 m)	Determine compressional wave velocities of shallow deposits; locate 30' and 100' (9 and 30 m) depths to rock (material with velocity >7000'/sec.; 2134 m/sec)	Suited to dry alluvium over rock; good results with accuracies generally within 10%	Access to perimeter sites in remote areas requires a great deal of time; actual performance rapid under normal circumstances	Very useful; should be fully integrated with drilling program; should run lines in interior parts of basin as well as perimeter lines; a must for determining construction conditions

GEOPHYSICAL METHODOLOGY EVALUATION (Continued)

METHOD/QUANTITY	OBJECTIVE(S)	EFFECTIVENESS	COMMENTS	APPLICATION TO VALIDATION
Downhole Seismic Velocity Measurements/11 borings	Establish P&S wave velocities and determine dynamic elastic moduli of interrogated materials (to 500' deep)	Average velocities obtained if thin interbeds encountered; quality of results varied; consistently obtained poor record quality in ungrouted holes	Best method of obtaining P&S wave velocities at economical cost; PVC should be grouted before performing test	Should be used in selected borings to help establish construction zone parameters
Downhole Geophysical Logging Techniques/ caliper, gamma-gamma, delta-gamma, neutron-gamma, neutron-epithermal-neutron, natural gamma; 23 borings	Establish feasibility for obtaining quantitative physical parameters of soils which otherwise are obtained by sampling and laboratory testing; analysis of stratigraphic continuity, determine depth to and thickness of ground-water zone	Little use for establishing stratigraphic continuity in alluvial deposits in widely separated borings; moderately effective for determining presence of ground water; measured responses and resolution insufficient to provide reasonable quantitative measurements of engineering soils properties	Better suited to stratigraphic conditions between more closely spaced borings; mobility of equipment relatively good; inexpensive relatively to total project cost, however, it requires casing of borings that would otherwise not require it, and other logistical support; field logs inadequate for detailed analysis; require computer enhancement, results moderately to highly interpretative	In general, the results do not sufficiently justify their use; not recommended for Validation studies

ENGINEERING GEOLOGY METHODOLOGY EVALUATION

METHOD/QUANTITY	OBJECTIVE	EFFECTIVENESS	COMMENTS	APPLICATION TO VALIDATION
Existing data gathering; local and regional publications, data, and maps	Provide background and accurate planning base	Very effective for investigation planning base; most data good for rock descriptions and structure; little direct data on properties of Valley fill, ground water	Prevents duplication effort; permits accurate planning	Excellent; a literature search was performed in the Characterization studies; a more detailed search should be made during Validation if there is a possibility of reducing the amount of field work
Photogeology/entire Valley; 1:24,000 color and IR stereo-pairs	Delineate mappable units; define areas of potential hazard and difficult construction; identify terrain characteristics, and locate field data collection points	Extremely effective; color photos provide an excellent medium for delineating fan units at an ideal scale; IR did not generally add to the data base established from normal color in this Valley	Provides basis for accurate depiction of units, hazards & structure; good scale; IR could be tested again in a different physiographic section if one is selected for Validation studies	Excellent for all Validation area; best method of evaluating large land areas
Field Reconnaissance Local and regional/ 2-2 man teams	Determine activity locations and access; define problem areas, familiarization with terrain and geotechnical conditions	Very effective; provided ground access is reasonable; aerial reconnaissance provided good overview for planning of mapping program	Enhanced through careful use of air support; a necessary step in planning an effective field mapping program	Ground and aerial reconnaissance suggested for all areas within CSR well prior to planning a major field program
Field Mapping/ 250 nm^2 (402 km^2) 2-2 man teams	Verify and supplement the results of photogeology; determine final locations for field activities	Excellent results; 2 teams of 2 men provide excellent areal coverage; very effective in documenting, modifying and validating interpretations made during photogeologic study	Provides excellent data base for Valley characterization; is needed to verify photogeology interpretations and to make detailed observations of actual field conditions and potential geologic hazards	Excellent and necessary for all validation studies; the degree of mapping detail will vary with complexity of surficial geology, structure, and hard rock geology

ENGINEERING GEOLOGY METHODOLOGY EVALUATION (Continued)

METHOD/QUANTITY	OBJECTIVE	EFFECTIVENESS	COMMENTS	APPLICATION TO VALIDATION
Characterization of borings & trenches/ 23 trenches; 39 borings	Provide engineering geologic characterization of subsurface soils engineering data	Good results; most effective with trenches, moderately effective with auger borings, limited effectiveness with wash borings	Is best performed by mapping team, but difficult to efficiently coordinate a part-time effort with drilling program; trenches provide best exposures for comparison with surficial features mapped by geologists	Necessary to relate and extrapolate engineering properties to mappable geologic units; geologic mapping should precede where possible

SOILS ENGINEERING METHODOLOGY EVALUATION

METHOD/QUANTITY	OBJECTIVE	EFFECTIVENESS	COMMENTS	APPLICATION TO VALIDATION
Shallow borings hollow stem auger <100'/ 30	Characterize and determine physical properties of geologic units and shallow subsurface soils units; determine depth to ground water; obtain undisturbed and bulk samples	Characterization not effective if geologic unit very thin or covers a large area with a variety of soil conditions; drilling method relatively fast and well suited to identifying subsurface units to 50' or 100'; generally not effective below 100' because of slow drilling rate	Equipment has good mobility in soft soil; drilling method is economical since no drilling fluids are required; good determination of moisture content and ground-water level	Well suited when combined with other exploration methods; should not be used for depths much greater than 100'
Deep borings rotary wash >100'/ 9	Characterize and determine physical properties of geologic units and deep subsurface soils units; determine depth to ground water and depth to rock; obtain undisturbed samples	Poorly suited for geologic characterization; well suited for obtaining undisturbed samples and characterizing deep subsurface units	Need water truck for drilling; need good access to drilling site when roads cannot be built; more expensive than hollow stem auger drilling	Best method for deep drilling and sampling for V&H assessment; better to use air for drilling but application and efficiency is limited to a few soil types and by depth
Trenches/23	Characterize and determine physical properties of geologic units and shallow subsurface soils units; obtain bulk samples; evaluate cementation, excavatability and slope stability to a maximum of 25'	Very effective for characterization and identification of shallow units; can obtain good bulk samples of coarse materials; effective in evaluating cementation, excavatability, and slope stability	Expensive operation for depths >10' to 15'; slow operation if trench shored for detailed logging; track-mounted equipment needed where soft surface soils; extensive time needed to move between distant locations	Should definitely be used and integrated with drilling, shallow refraction, and geologic mapping

SOILS ENGINEERING METHODOLOGY EVALUATION (Continued)

METHOD/QUANTITY	OBJECTIVE	EFFECTIVENESS	COMMENTS	APPLICATION TO VALIDATION
Undisturbed soil samples/201 Pitcher samples; 171 Fugro drive samples	Perform laboratory tests on samples to determine engineering properties	Pitcher samples best for unit weight, shear strength, and consolidation tests; not effective for moisture content because of drilling fluid infiltration; Fugro drive samples from hollow stem auger borings best for moisture determination, but samples disturbed during driving; split spoon samples obtained in clean sands or gravels when other sampling methods not effective	Can eliminate moisture contamination of Pitcher samples by drilling with air; method limited to few soil types and is more expensive; cannot obtain Pitcher samples through hollow stem augers because inside diameter too small	Undisturbed samples essential for determining many soil properties
Bulk (disturbed) samples/32 from trenches, 24 from auger holes	For classification, determination of compaction, CBR characteristics, and suitability as an aggregate source	Best samples obtained from trenches; can obtain cuttings from hollow stem auger holes; cannot obtain sufficient amount of material in rotary wash borings	Large samples (50 lbs.) needed in coarse materials - trenching is best method; bulk samples only needed in upper 20 feet	Bulk samples needed for road design and suitability of materials for base course, concrete and backfill
Laboratory testing/ 12 types of physical tests, 4 types of chemical tests	To determine engineering properties of subsurface units preliminarily to evaluate construction feasibility, provide data needed for V&H evaluations	Effectiveness depends on suitability of samples for measuring important parameters; limitations of sampling methods listed above; combination of sampling methods provides suitable results	Field laboratory near site area only effective if extensive study done in one area; well designed shipping boxes are essential to minimize sample disturbance during transport	Laboratory testing essential for determining soil properties, estimating construction costs, providing data for V&H evaluation

3.0 GEOPHYSICAL INVESTIGATIONS

3.1 DEEP SUBSURFACE PARAMETERS

3.1.1 OBJECTIVES AND SCOPE

Three techniques of geophysical investigation were used to obtain information relating to the large-scale deeper features of the Lechuguilla-Desert Basin. The techniques were seismic refraction, gravitational field measurement and magnetic field measurement. Drawings presenting the interpretations derived from these investigations are included in Appendix A.

Two long ("deep") seismic refraction lines were recorded in order to obtain generalized compressional wave velocity profiles, calculate depths to basement, and aid in the interpretation of gravity data. Line LD-DS-1 with a bearing of N25W was 35,600 feet (10,854m) long and line LD-DS-2 with a bearing of N40E was 26,800 feet (8171m) long. The geophone interval for both lines was 200 feet(61m). Procedures followed are described in Appendix D of FN-TR-18 and the locations of the lines are shown on Drawing 1. The lines are located such that they intersect at geophone position 169 on line LD-DS-1 and at geophone position 133 on line LD-DS-2.

Observations of the gravitational field were made in order to estimate the depths to basement and to define the gross basin shape. The measurements were made on a nominal one statute mile (1.6 km) grid spacing. A total of 241 stations were occupied. The gravity observations were related to the International Gravity Standardization Net (1971) by referencing the readings to Base Station R-257, 1945, Yuma International Airport. This

station is referenced as ACIC 0446-1 by the Defense Mapping Agency (DMA). The gravity stations occupied in this survey are shown on Drawings A-1, A-2, and A-3 (Appendix A). The procedures followed for obtaining and reducing the gravitational field data are described in Appendix D Supplement.

Magnetic field measurements were made with an airborne magnetometer to permit gross estimates of the depth to and configuration of the basement rock surface and to obtain indications of shallower intrusive or volcanic extrusive bodies. Aeromagnetic measurements were made in March 1977. The flight lines were perpendicular to the Valley axis and spaced at one-half statute mile (0.8 km) intervals. Nominal flight altitude was 500 feet (152 m). Appendix D (FN-TR-18) describes the procedures followed for the aeromagnetic measurements. No magnetic field measurements were made on the ground in Lechuguilla Desert.

3.1.2 DEEP VELOCITY PROFILES

The compressional wave velocity profiles obtained from seismic refraction lines LD-DS-1 and LD-DS-2 are shown in Appendix Figures A-1 and A-2, respectively. Line LD-DS-1 shows five velocity layers overlying a high velocity layer, interpreted to be crystalline basement or the basin floor. Line LD-DS-2 shows four layers (one less than LD-DS-1) overlying the basin floor. The difference in the number of layers mapped on the two lines is due to the presence of an intermediate (fourth) layer between the third and fifth layers on line LD-DS-1. This layer becomes very thin, and eventually "pinches out", near the tie

point of the two lines, and, is therefore not detected on line LD-DS-2. With the exception of this intermediate layer, all other layers are correlative between the two lines. The basement interface as interpreted from the refraction surveys, agrees within less than 10% difference at the tie point.

It should be noted that the thin surficial layer (approximately 20 feet thick; 6 m) with velocities in the range of 1200 to 1650 feet per second (366 to 503 m/sec) detected on the short perimeter refraction lines and downhole velocity surveys could not be detected on the Valley refraction lines because the geophone interval used was much greater than its thickness.

The shallowest layer velocity shown on the long seismic profiles ranges between 2900 and 3300 feet per second (800 and 1006 m/sec) and its calculated thickness varies from 0 to 300 feet (0 to 91 m). This layer overlies a second layer with velocities in the range between 3500 and 4500 feet per second (1070 and 1372 m/sec). The calculated thickness of the second layer is from 300 to 600 feet (91 to 182 m). Both of these uppermost layers are shown to be continuous and are traceable over the extent of each seismic line. They are thought, in general, to represent alluvial fan deposits and playa/lacustrine materials.

The velocity of the shallowest layer on the Valley profiles is, in most cases, about 20 percent lower than that observed for the same zone in most of the downhole velocity surveys. While some of the differences can certainly be associated with the variations in material at the different survey locations, much of the difference is related to the survey methods

used. That is, the downhole method measures velocities of vertically travelling waves within a small area while the refraction method averages measurements of horizontally travelling waves over relatively large distances.

The third layer is shown to have velocities from 6900 to 7200 feet per second (2100 - 2190 m/sec) on line LD-DS-1 and from 7400 to 7500 feet per second (2256-2287 m/sec) on line LD-DS-2. While the layer three velocities measured on line LD-DS-2 are slightly higher than those measured on line LD-DS-1, the difference is small enough to be considered insignificant. This layer has a maximum thickness of approximately 1400 feet (427 m) as shown on the LD-DS-2 profile. It increases from 0 thickness on the eastern, western and southern ends of the seismic lines to maximum thickness in the center of the valley. Layer three shows a gentle shallowing trend to the north on line LD-DS-1, but does not become thinner than 600 feet (183 m) at the northern extremity of the line. This layer may represent well indurated alluvial fan/fanglomerates, the youngest of which are exposed at some locations on the Valley periphery.

The fourth velocity layer, shown only on line LD-DS-1, has a velocity of 9700 feet per second (2960 m/sec). It increases from zero thickness beneath geophone position 160 to a maximum thickness of about 1200 feet (366 m) in the northern third of the line. This intermediate layer, as discussed above, is not detected on line LD-DS-2 because the layer has become too thin at the point at which the lines intersect. The material represented by this velocity may be highly indurated fanglomerate, sedimentary

bedrock or igneous rock.

The fifth velocity layer of line LD-DS-1 and the fourth velocity layer of line LD-DS-2 are correlatable and exhibit velocities in the range from 13,000 to 14,800 feet per second (3960 to 4510 m/sec). Both lines show this layer to have considerable thickness (approximately 4000 feet; 1220 m) near the tie point. This zone could represent sedimentary bedrock or igneous intrusive material.

The deepest layer detected has a velocity of approximately 16,500 feet per second (5030 m/sec) and is interpreted to represent crystalline basement. Line LD-DS-2 shows the top of basement to dip approximately 25° northeast towards the basin center. The eastern end of line LD-DS-2 shows the basement surface to rise at a lesser rate as far as the line extends. Line LD-DS-1 confirms the trend of the basement interface deepening towards the center of the basin. The degree of dip shown on the north-south (valley axis) section (LD-DS-1) is much less than that shown on the east-west (perpendicular to valley axis) section (LD-DS-2).

3.1.3 DEPTH TO CRYSTALLINE BASEMENT INTERPRETATION

3.1.3.1 Seismic Refraction Evidence

The depth to the highest velocity layer (interpreted to be crystalline basement) reaches a maximum of about 6000 feet (1829 m) beneath seismic lines LD-DS-1 and LD-DS-2. The western flank as shown on line LD-DS-2 dips into the valley at approximately 30° East and the southern flank as shown on

line LD-DS-1 dips into the valley at approximately 10° South. The other flanks also show a general shallowing trend. The shot to detector offset distances are sufficiently long for both lines to permit the detection of continuous refraction arrivals from this layer for distances of several thousand feet (meters). Reversed coverage along a common portion of the interface was obtained only on LD-DS-1.

The shape of the bedrock and basement surface shown on the seismic refraction profiles suggests a closed basin structure. Such a structure is supported by the gravity and magnetic interpretations of the basement interface.

3.1.3.2 Gravity Field Evidence

A contour map of Bouguer anomaly is presented in Drawing A-1. The contour lines superimposed on this map (short dashes) represent the zero value of the second vertical derivative (SVD). The SVD is explained in Appendix D Supplement.

The interpretation of depth to basement is based on isolating a negative residual anomaly intended to represent lightweight alluvial material over heavier basement rock. The presence of the thick, high velocity layer number five overlying yet another higher velocity layer on the seismic refraction profiles raises an important question. Layer number five almost certainly has a markedly higher density than overlying layers, but is probably less dense than the underlying layer. The question is then, does the residual anomaly represent a contrast

between layers 1 to 4, and 5, or between layers 1 to 5, and 6.

Two lines of evidence favor the latter choice. Qualitatively, the gradients on the residual map suggest considerable relief, and the relief shown for layer 6 on the refraction profiles is much greater than on layer 5. Additionally, downward continuation analyses indicate that the gravitational field can be successfully continued in this part of the area to depths of approximately 7000 to 8000 feet (2300-2600 m).

An interpretation of the depth to basement is presented by the contour map of Drawing A-2. This map is based on a residual gravity field which was isolated from the Bouguer anomaly by subtracting a regional gravity field. The regional gravity was generated by fitting a second order polynomial surface to the Bouger anomaly values at gravity stations taken on bedrock. The residual gravity values at each station were converted to depth using an abbreviated version of the Bouguer slab equation (see FN-TR-18, 3.1.3.2).

The density contrast used in the depth to basement calculations was -0.26 grams/cm^3. It was chosen to provide the best overall correlation with the boring and seismic refraction data as well as the result from downward continuation analysis. Cross sectional views of the gravity fields and the interpreted basin shape are given along profiles LD-G/MP-AA' and LD-G/MP-BB' (Figures A-3 and A-4).

The deepest part of the basin lies south of the Wellton Hills and is designated L_1 (see Drawing A-2). The basin is a closed feature with its axis trending about N45°W. It is bounded to the west, north and east by steep gravity trends, typical of those produced by basin and range faults. Its SE end shows a moderately dipping (less than 15°) trend to the NW. Its greatest apparent depth is about 7500 feet (2286 m). The apparent steep slope into the basin along its southwestern flank, may in reality represent a near-vertical fault following the zero SVD contour (see Drawing A-1), which is approximately along the 2500 depth contour level of this map.

Another prominent feature of the map (Drawing A-2) is an almost circular "mound", designated as H_1, extending eastward from the Gila Mountains, and centered in the Wellton Hills. The south flank of tl᠆ "mound" appears to dip strongly. The tightest contours, as indicated by the SVD, occur at about latitude 32° 31.3'. In actuality, this flank may represent an east-west trending fault of considerable vertical displacement (as much as 3000 feet; 914 m).

A narrow trough designated L_2 is indicated east of the mound (H_1). The axis of this trough is oriented slightly west of north.

3.1.3.3 Aeromagnetic Field Evidence

The following discussion will be based largely on the "residual magnetic intensity" map (Drawing A-3). This map displays magnetic anomaly components of "high spatial frequency", which are

characterized by numerous circular or oval closed loops, becoming convoluted and complicated in appearance. These high frequencies are associated with relatively shallow sources, less than say 600 feet (183 m) in depth. Low frequency anomalies usually are related to sources at greater depth, but it is possible for shallow sources to appear as low frequency anomalies. In addition to Drawing A-3, a "low pass" (Fourier Transform-derived) filtered map of the magnetic field was used in this study to accentuate the lower frequency anomalies. The filtered map is not included in this report since Drawing A-3 contains all the information, and with some study, it is possible to visually pick out low frequency trends. The following discussions will point out where interpretation is based on the low frequency aspect of the magnetic field. A large number of depth estimates were obtained by Geometrics using their proprietary procedure called "CompuDepth". These results are included in the discussion.

On the residual magnetic anomaly map a number of areas are numbered and/or encircled, and two axes are marked. These areas are numbered for the purposes of discussion.

It is expected that high frequency magnetic anomalies may represent basalt flows or shallow intrusions. An example of this can be seen in Area #1 (centered at approximately latitude 32° 24′, longitude 114° 06-1/2′) which is clearly associated with Raven Butte, a basalt flow. The anomalous area as seen on the magnetic map is somewhat larger than the exposed flow.

This feature displays "polarity": a magnetic high on the west (magnetically south) side, and a magnetic low on the east (magnetically north) side. This would correspond to induced magnetization in the direction of the present Earth's field of a tabular body.

Raven Butte basalt flow appears to originate at the mountain front and extend eastward into the valley. It is possible that the mountain front is closely associated with a high angle fault, down to the east, and that the basalt was extruded along the fault plane. Other magnetic features may have a similar origin.

Borehole LD-D-2 which encountered basalt at a depth of 814 feet (248 m) is located in the eastern part of Area #2 (latitude 32° 32-1/2', longitude 114° 03'). The elongated part of Area #2 was drawn, observing the indicated polarization, on the assumption that this is representative of a basalt intrusion or dike. As in the case of Raven Butte (Area #1) the causative feature need not be as wide as the magnetically anomalous field. Geometric's "CompuDepth" suggests the following depths to this magnetic source: on the west 492 feet (150 m), near the center 656 feet (220 m), and on the east 328 feet (100 m).

Area #3 (latitude 32° 28-1/2', longitude 114° 10') is an elongate zone suggestive of a basalt (?) intrusion or dike along a fault plane just east of the mountain front. (CompuDepth indicates a depth to this magnetic anomaly of zero at the north end, and 492 feet (150 m) at the south end).

Area #4 (latitude 32° 31', longitude 114° 12' to latitude 32° 30-1/2', longitude 114° 14') contains a very steep elongate (E-W) gradient suggesting shallow (CompuDepth estimates zero depth) intrusions which may be aligned with the elongate part of Area #2. This may lie along a fault line suggested by topography at the mountains and by the gravity observations (and SVD) south of the Wellton Hills outcrop.

Area #6 (latitude 32° 32-1/2', longitude 114° 13-1/2') (CompuDepth zero) is associated with exposed rocks of the mountain front and the Sheep Mountain Fault. The high frequency pattern and steep gradients in the field are similar to those south of Area #4. The high frequency pattern in Area #6 extends farther east than the similar patterns to the south. This seems to agree with the suggestion of a horizontal component of fault displacement which is also seen in the topography here.

Area #7 (latitude 32° 23-1/2', longitude 114° 02-1/2') represents a buried feature (CompuDepth estimates 492 feet (150 m) depth) outside the area of the gravity survey, so there is no confirmation of its significance. It displays polarity suggestive of a tabular intrusion.

Area #8 (latitude 32° 33-1/2', longitude 114° 07') displays a moderately high frequency pattern which causes it to make a visual contrast with the surrounding portions of the residual magnetic intensity map. It suggests a rather flat magnetic body (CompuDepth indicates 328 feet (100m) on the west, zero

in the center, and 656 feet (200 m) on the .ast). In this respect it is to some extent in agreement with the gravity interpretation: the basement depth contours indicate a lower dip in the center of this area than they do elsewhere on the "mound" (H_1 on Drawing A-2). The magnetics thus tend to strengthen the idea that the mound is flatter than depicted on Drawing A-2, and therefore supports the gravity interpretation suggesting the southern flank is a fault controlled structure.

Area #9 (latitude 32° 39', longitude 114° 06')is a feature where an apparent shallow bouguer gravity anomaly is nearly coincident with a zone indicated as zero depth by the CompuDepth procedure. It is likely that it corresponds to a very shallow intrusion of massive material (basalt ?). This feature lacks the high frequency components which seem to be characteristic of shallow tabular flows or intrusions. Possibly the flight lines were so spaced here that the high frequency contributions to the field were undetected.

Area #10 (latitude 32° 27', longitude 114° 03') probably corresponds to a shallow tabular intrusion of heavy magnetic material (basalt ?) (CompuDepth estimates zero depth to the east, and 492 feet (150 m) in the center of this area). The associated gravity anomaly suggests that it thickens toward the east where its effect may tend to lessen the gradients obtained in the gravimetric basement analysis and possibly cause the calculated depth to basement beneath the intrusion to be less than the actual depth.

Area #11 (latitude 32° 28', longitude 113° 58') falls on the mountain outcrop. It is suggested that this anomaly represents a shallow tabular intrusion of massive magnetic material (basalt ?). This appears to be associated with the west flank of the Copper Mountains which is probably faulted (steeply down to the west) along this feature. This feature is near the outer limits of gravity observations.

In addition to the indicated shallow anomaly, there is a strong low frequency magnetic high along this portion of the mountain front. The interpretation that major faulting exists parallel to this axis is supported by the strong eastward magnetic (decreasing) gradient; this is suggestive of a large vertical displacement of magnetic material at considerable depth. (In the present Earth's field, such a displacement would produce a positive (high) induced field with its axis parallel to the fault).

Another low frequency feature is the marked linear magnetic low beginning at approximately latitude 32° 30', longitude 114° 10', which extends approximately 14 nautical miles (26 km) in the approximate direction S 30° E to nearly latitude 32° 20'. (The Raven Butte basalt flow lies over this axis, its magnetic expression being superimposed on the low frequency magnetic axis). This low frequency axis is marked by the dashed line (Drawing A-3) along the east front of the Gila and Tinajas Altas Mountains. Again, assuming induced magnetism in the earth's present field, this is interpreted as the expression

of a near-vertical fault (down to the east) in magnetically susceptible rocks over a considerable depth range.

To the north another low frequency, magnetic low axis parallels the Gila Mountains front through approximately latitude 32° 35', longitude 114° 15'. It cannot be followed southeast of Area #6 across the inferred possible west-east fault.

Area #12 (latitude 32° 36-1/2', longitude 113° 59'), contains a steep aeromagnetic gradient between a distinct low on the southwest and a distinct elongate high on the northeast. This suggests a northwest trending fault block (graben) which has dropped, displacing magnetic rocks on both the southwest and the northeast sides.The surface outcrop here is of sedimentary origin, so the magnetic rocks are probably beneath them. [CompuDepth finds a depth of approximately 164 feet (50 m)].

Area #13 (latitude 32° 37-1/2', longitude 114° 12'), shows a steep gradient between an elongate high on the southwest to a (non-parallel) elongate low on the northeast. This area has the appearance of an uplifted magnetic body with induced magnetism in the present Earth's field [CompuDepth estimates depths of 328 feet (100 m) on the northwest, and 984 feet (300 m) on the southeast]. This area conforms approximately with the northwest "nose" of the central mound (H_1 on Drawing A-2) depicted by the gravity basement interpretation and is also outlined by the zero contour of the SVD of the Bouger anomaly field.

The highest observed intensity of the residual magnetic field occurs at point 5 (approximately latitude 32° 27.2', longitude 114° 06.8'). This point is slightly west of the basin (L1 on Drawing A-2) axis as suggested by the gravitational basement depth interpretation. Near this point, the contoured magnetic field (low pass filter) is elongate in a north-south direction, and its east flank is much steeper than its west flank. This suggests a wedge-shaped magnetic body, with the narrow edge of the body toward the west flank of the basin, and the thick end (and termination) toward the east flank, approximately a mile 2 km) from the basin axis. Approximately a mile (2 km) north of the magnetic apex, the shape of the contours of the magnetic field conform closely to the basement depth contours derived from the gravimetric interpretation. It is suggested that this magnetic source is an intrusion of basalt (?) originating perhaps at the postulated fault on the west side and flowing over the whole basement contact (between it and overlying alluvium) in the northwestern end of the basin.

3.2 SHALLOW SUBSURFACE PARAMETERS

3.2.1 OBJECTIVES AND SCOPE

One technique used to obtain compressional wave velocities in the shallow subsurface materials consisted of seismic refraction surveys utilizing relatively short (25 feet; 7.6 m) geophone spacings. The procedures used to layout and record the perimeter seismic lines are described in Appendix D (FN-TR-18). The locations of these lines are shown on Drawing 1. Thirteen short seismic lines were distributed around the perimeter of the Valley. In addition, two lines of intermediate [geophone spacing of 100 feet (30 m)] length were completed. The primary purpose of these perimeter lines was to locate points around the Valley where rock was 30 and 100 feet (9 and 30 m) deep. For this purpose, rock was defined as material with seismic compressional wave propagation velocity greater than 700 feet per second (2134 m/sec). These lines were generally placed near outcrops of crystalline rock and extended toward the Valley interior.

Downhole velocity surveys were made in eleven borings to measure compressional and shear wave velocities in the shallow subsurface materials. The maximum depth surveyed was approximately 490 feet (149 m). The procedures followed are described in Appendix D (FN-TR-18).

Nuclear geophysical logging techniques were used to obtain data which could be related to physical parameters, such as moisture content, porosity and bulk density. Gamma-Gamma, Delta Gamma, Neutron Gamma, Neutron-epithermal-Neutron, Natural Gamma, and

Caliper logs were run in 16 of the engineering borings in Lechuguilla Desert. The logs and logging procedures are briefly described in Appendix D (FN-TR-18).

The intent of the logging program in this methodology study is to establish the feasiblity of using the logs for obtaining quantitative physical parameters of the soils, which otherwise are obtained by sampling and laboratory testing. A common application of borehole logs is to make stratigraphic correlations from boring to boring. As was the case in Mohawk-Tule Valley, the alluvial deposits in Lechuguilla were expected to have limited lateral continuity making definitive correlations over any distance very difficult.

3.2.2 DEPTH TO ROCK AT PERIMETER

The profiles interpreted from the 15 (includes intermediate lines) perimeter seismic lines (Drawing 1) are included as Appendix Figures A-5 through A-19. Compressional wave velocities representative of rock were observed on all of the lines.

Lines LD-S-4, LD-S-9, and LD-S-10 were the only lines on which velocities greater than 8200 feet per second (2500 m/sec) were not measured. These lines were positioned close enough to out-crops of metamorphic or igneous rock to have measured representative velocities of those rock types. It is therefore assumed that the velocities that were measured, while abnormally low, represent weathered igneous rock instead of sedimentary units. This is apparently verified on line LD-S-4 where boring LD-B-1 penetrates highly weathered granite at a depth correspond-

ing to the 7500 foot per second (2287 m/sec) layer. The lower velocities are therefore, probably due to a high degree of weathering of the basement materials. In summary, all perimeter lines are interpreted to have detected crystalline basement although the velocities vary due to differing degrees of weathering.

3.2.3 SHALLOW VELOCITY PROFILES

The compressional wave velocity distribution for materials overlying the crystalline basement around the valley perimeter is provided by fiften seismic refraction lines and eleven downhole velocity surveys. The velocity profiles (Figures A-7 through A-21) indicate six velocity layers which overlie basement, although no one line shows evidence of all layers. Surficial layer velocities were calculated to be between 1200 and 1650 feet per second (366 to 503 m/sec) on all the perimeter lines, except LD-IS-1, LD-S-6, LD-S-8, and LD-S-13, where they appeared to be somehat higher (1850 to 2200 feet per second or 564 to 671 m/sec). The lower velocities probably represent a weathered near-surface zone, but they may be typical of the youngest uncemented fan unit (A5y). The higher surficial velocities may indicate that these lines are over different units, or that the near surface cementation is slightly greater in these locations. Another possibility is that the upper layer is so thin that the travel time observations used to calculate these velocities were influenced by the underlying higher velocity material. This is especially likely for line LD-IS-1 because its geophone spacing of 100 feet (30 m) considerably exceeds the surficial layer thickness.

All downhole surveys indicate a surficial layer (25 feet or less in thickness) with velocities in the range ofrom 1175 to 1800 feet per second.

Exclusive of the uppermost layer, eleven of the profiles (LD-S-1, LD-S-2, LD-IS-1, LD-S-4, LD-S-5, LD-S-6, LD-S-7, LD-S-9, LD-S-12, LD-S-13, and LD-IS 2) indicate only one velocity associated with sedimentary materials, and the other four (LD-S-8, LD-S-10, LD-S-11, and LD-S-14) indicate two velocity layers above crystalline basement.

A summary of the velocity distribution determined from the perimeter seismic lines is presented in Table 2. The results of the downhole velocity surveys are summarized in Table 3.

Results of individual downhole velocity surveys are presented in Figures A-20 through A-30. In general, the velocity distribution determined by the downhole surveys agrees with that of the perimeter refraction surveys. No hole in which a downhole velocity survey was conducted was located on a perimeter refraction line. However, borings LD-B-1 and LD-C-3 were located close to lines LD-S-4 and LD-S-9 respectively. In general, the velocities determined from the downhole surveys are about 20 percent less than those shown on the refraction profiles. This small difference is normal due to differences in the two methods used to make the measurements. The downhole survey can be considered a "point" study restricted to the area surrounding the boring while tne refraction survey is a "line" study which averages velocities beneath the entire seismic line.

Mean Velocities (ft/sec) / (m/sec) + 10%	1	IS-2	2	IS-1[1]	4	5	6	7	8	9	10	11	12	13	14
	Seismic Refraction Lines														
1500 / 457	X	X	X		X	X		X		X	X	X	X		X
2000[2] / 610				X			X		X					X	
3000 / 914					X	X		X		X			X	X	X
4000 / 1219		X							X		X	X			
5000 / 1524			X								X				X
6500 / 1982	X			X	X		X		X			X			
8500[3] / 2591		X								X	X		X		
9500-14,500 / 2896-4421	X	X	X	X		X	X	X	X			X		X	X

1. LD-IS-1 with geophone spacing = 100 feet replaces LD-S-3
2. See discussion in Section 3.2.3
3. Highly weathered basement

COMPRESSIONAL WAVE VELOCITY DISTRIBUTION ON PERIMETER REFRACTION LINES LECHUGUILLA DESERT, ARIZONA

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TABLE 2

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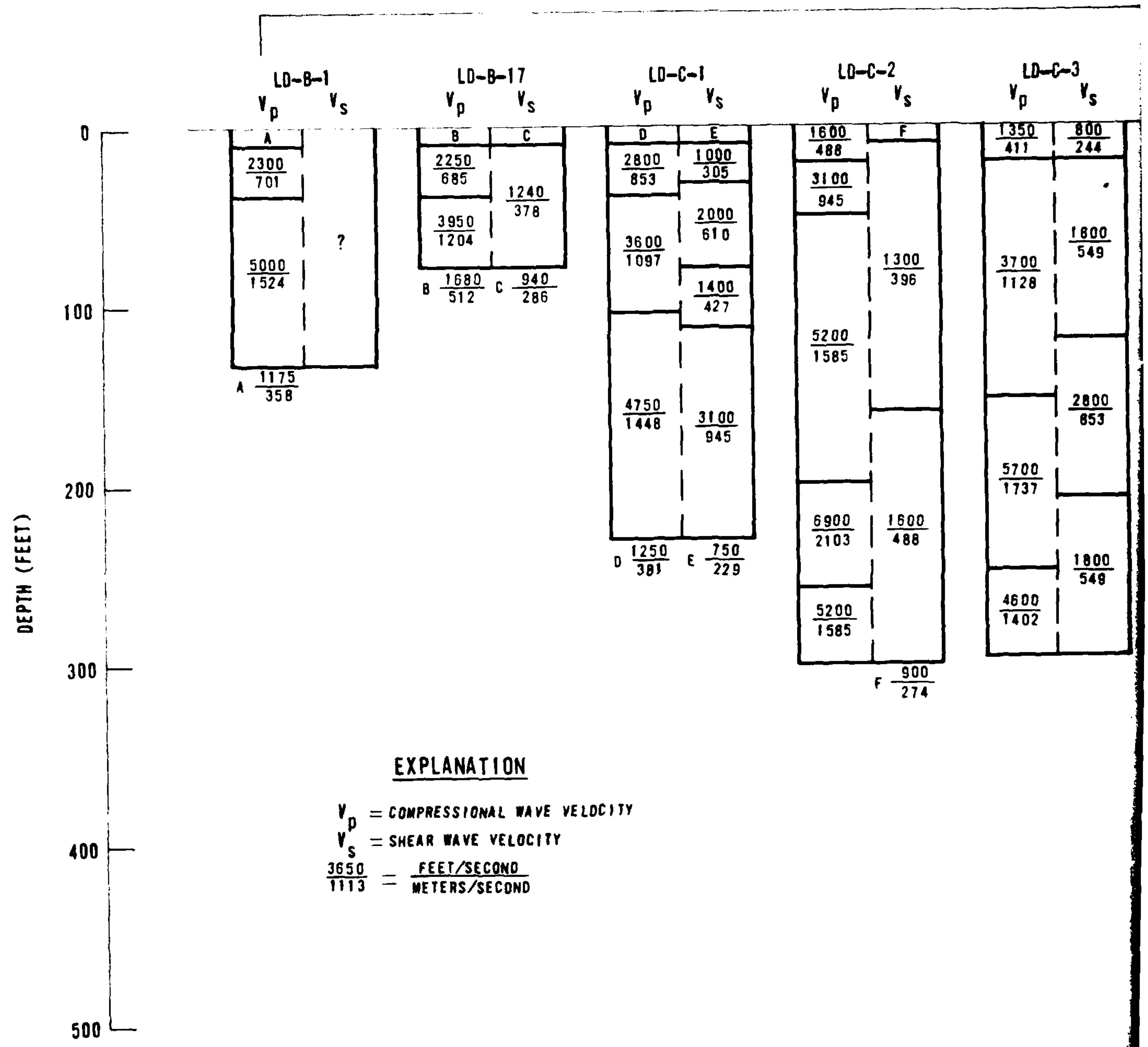
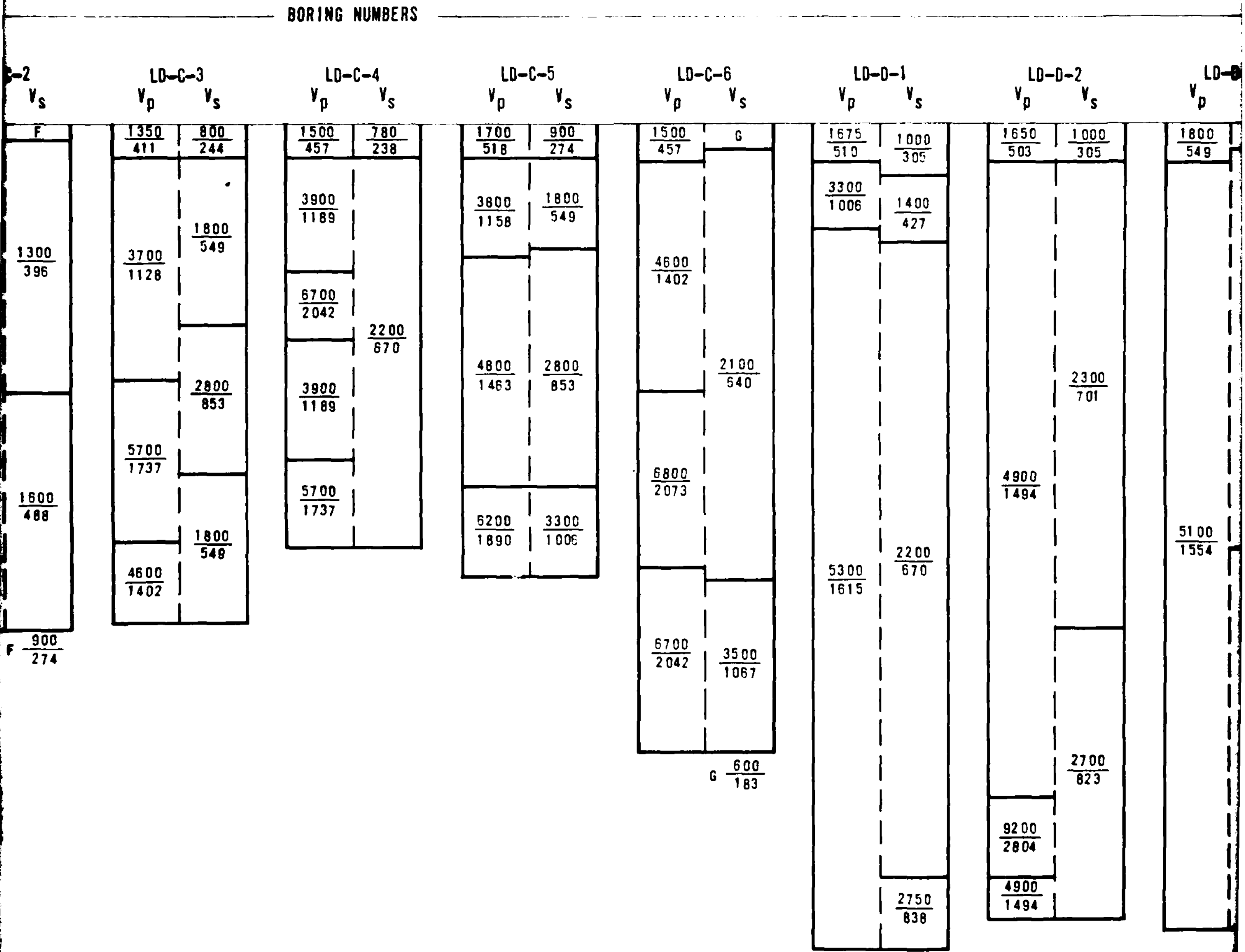


EXPLANATION

V_p = COMPRESSIONAL WAVE VELOCITY

V_s = SHEAR WAVE VELOCITY

$\frac{3650}{1113} = \frac{\text{FEET/SECOND}}{\text{METERS/SECOND}}$



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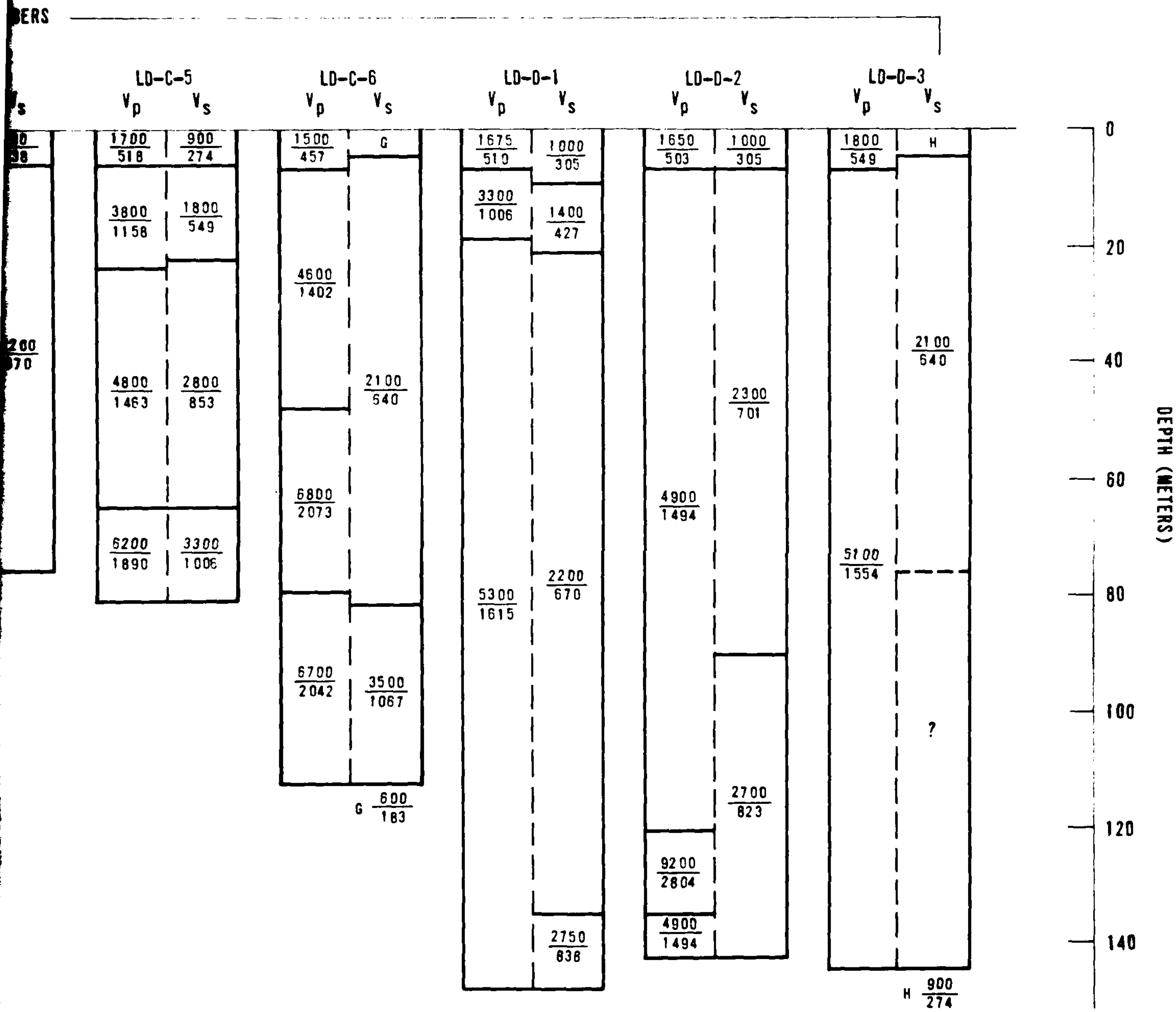

SUMMARY OF RESULTS - DOWNHOLE VELOCITY SURVEY LECHUGUILLA DESERT, ARIZONA

MX SITING INVESTIGATION DEPARTMENT OF THE AIR FORCE - SAMSO	TABLE 3

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2

3

Downhole velocity surveys were performed to obtain shear wave velocities as well as compressional wave velociteis for shallow (less than 500 feet; 152 m) subsurface materials in the Valley. The interpreted data plots from the surveys are shown in Apppendix Figures A-20 through A-30. The results are summarized in Table 3.

The average distance between the borings in which the downhole velocity surveys were conducted was approximately four miles. Generalization for an area as large as Lechuguilla Desert is highly interpretive, especially based upon such widely spaced sampling points. However, a composite velocity profile representative of typical compressional wave and shear wave velocities is shown in Table 4. The composite results indicate five velocity layers which typify Lechuguilla Desert. The compressional wave and shear wave velocities for these layers are 1600, 2200, 3700, 5000, and 6500 feet per second (488, 671, 1128, 1524, 1981 m/sec) and 950, 1250, 2000, 2500, and 3300 feet per second (290, 381, 610, 762, and 1006 m/sec) respectively. A velocity in excess of 7000 feet per second (2134 m/sec) was detected in only one boring, LD-D-2. In general, the velocities shown on the composite summary are in good agreement with the velocities determined by the perimeter refraction lines.

Notable exceptions to the typical profile are borings LD-C-6, LD-D-2, and LD-D-3. These profiles do not show evidence of the typical second or third velocity zones. Again, the composite represents a generalized section that could well be different from that at any specific location. Another anomalous velocity

LECHUGUILLA DESERT COMPOSIT

DEPTH (FT)	DEPTH (M)	P-WAVE VELOCITY (FT/S)	P-WAVE VELOCITY (M/S)	S-WAVE VELOCITY (FT/S)	S-WAVE VELOCITY (M/S)	UNIT WEIGHT (PCF)	UNIT WEIGHT (KG/CM)	POISS RATI
0 - 10	0 - 3	1600	488	950	290	116	1858	.22
10 - 20	3 - 6	2200	671	1250	381	116	1858	.262
20 - 50	6 - 15	3700	1128	2000	610	116	1858	.29
50 -150	15 - 46	5000	1524	2500	762	117	1874	.33
150 -500	46 -152	6500	1981	3300	1006	117	1874	.32

(INPUT)

DESERT COMPOSITE DOWNHOLE SURVEY

	UNIT WEIGHT (KG/CM)	POISSONS RATIO	SHEAR MODULUS (KSF)	SHEAR MODULUS (KN/SM)	YOUNGS MODULUS (KSF)	YOUNGS MODULUS (KN/SM)	BULK MODULUS (KSF)	BULK MODULUS (KN/SM)
6	1858	.228	3250	155518	7981	381875	4886	233785
6	1858	.262	5627	269248	14199	679385	9928	475035
6	1858	.294	14406	689276	37270	1783297	30096	1440035
7	1874	.333	22703	1086278	60540	2896741	60541	2896777
7	1874	.326	39557	1892730	104935	5020926	100729	4819660

(CALCULATED)

COMPOSITE SUMMARY OF VELOCITY VALUES AND DYNAMIC MODULI LECHUGUILLA DESERT, ARIZONA

MX SITING INVESTIGATION
DEPARTMENT OF THE AIR FORCE - SAMSO

TABLE 4

FUGRO NATIONAL, INC.

occurs in boring LD-C-1 from 110 to 230 feet (34-70 m) where the shear wave velocity was measured to be 3100 feet per second (945 m/sec). This value for the shear wave velocity appears to be too high for the corresponding compressional wave velocity and soil type over the same interval. The Poisson's ratio calculated for this interval is indicative of a highly cemented sandstone. The boring logs do indicate locally high cementation over the interval concerned which possibly contributes to the high velocity measured.

The quality of the seismograms for the downhole velocity surveys in the Lechuguilla Desert varied from good to unusable with most being from fair to poor. In a number of holes surveyed in the Lechuguilla Desert, background noise and possible poor coupling between casing and boring wall contributed to making the shear wave arrival difficult and in some cases impossible to distinguish.

3.2.4 DYNAMIC SOIL MODULI

Downhole velocity surveys were performed in eleven borings in the Lechuguilla Desert. The compressional and shear wave velocities determined from the surveys are summarized on Table 3. These velocities along with the measured material densities were used to compute the dynamic moduli for the subsurface materials. The results of the dynamic moduli computations are presented in Table A-1 (6 pages) in Appendix A. A composite summary of the downhole surveys typifying the dynamic moduli for Lechuguilla Desert is shown in Table 4.

The composite summary shows that velocities in the Lechuguilla Desert are within 10 to 20 percent of those in Mohawk-Tule Valley This is further illustrated in Table 1, Section 2.4.4 showing the typical engineering properties of the subsurface materials.

The formulae used in the computation of the dynamic moduli (Young's Modulus, Bulk Modulus, Shear Modulus) and Poisson's Ratio are given in Appendix D Supplement. No direct measurement of shear waves was made in Boring LD-B-1 nor for the interval from 150 to 480 feet (46 to 146 m) in Boring LD-D-3. In order to compute the dynamic moduli at these borings, a published empirical formula was used to calculate the shear wave velocity from the compressional wave velocity and unit weight for each particular interval. Calculated shear wave velocities are noted on the appropriate summary tables. An explanation of the method used for calculation of the shear wave velocities appears in Appendix D Supplement-6.3.

3.2.5 BULK DENSITY, POROSITY, AND PERCENT MOISTURE

Suites of geophysical logs for each borehole tested are shown in Appendix Figures A-31 through A-44 and Drawings A-4 through A-12. Comparison of the logs to the sample descriptions indicates that they do reflect lithology in a qualitative sense. The parameters which theoretically may be resolved from the radioactive log are moisture content, porosity, and bulk density. In order to obtain quantitative physical parameters from the logs, they must first be appropriately calibrated by comparison to laboratory-derived values. The relationships are described in Appendix A-7.

The procedures for achieving this calibration are currently under study. They are being based on statistical regression of the two sets of data. The study has not progressed to the point where geotechnical data are available for this report. The answer to the more important aspect of the applicability of the tool for future validation studies will be addressed in the Methodology Report. A positive result will permit the extension of a relatively few laboratory measurements to a near-continuous vertical representation of the physical environment.

4.0 ENGINEERING GEOLOGY INVESTIGATION

4.1 OBJECTIVES

The principal objective of the engineering geology investigation in Lechuguilla Desert was to provide a means for effectively extrapolating engineering properties of earth materials over large areas. In order to meet this objective, the following studies were performed:

1. Determination of the character, extent, and interrelationships of the surficial and subsurface basin-fill deposits and rock units;
2. Definition and delineation of specific areas of potential geologic hazards and difficult construction, e.g., playas, boulder fields, eolian deposits, capable faults, and high-flooding potential; and
3. Definition of the hydrologic (surface and subsurface) and terrain conditions of the study area.

The results of this investigation are discussed in detail in Sections 4.3 through 4.7.

4.2 SCOPE

4.2.1 GENERAL

To satisfy the objectives, several investigative procedures were utilized:

1. Evaluation of existing data;
2. Acquisition and compilation of new data; and
3. Analysis of all collected data

These efforts required both office and field activities. Existing data from previous investigations were available and evaluated at Fugro National, Inc. New data were obtained in the field, and were analyzed as an on-going process in the field and Long Beach offices of Fugro National, Inc. To facilitate the collection and compilation of new data, color and color infra-red stereo aerial photographs (scale 1:24,000) of Lechuguilla Desert were obtained.

4.2.2 EVALUATE EXISTING DATA

The initial phase of the engineering geology investigation involved the collection, review, and evaluation of existing data, e.g., reports, maps, and aerial photography. The primary reference was the MX Siting Investigation: Geotechnical Evaluation of Department of Defense Lands, Volume IIB, Geotechnical Report, Yuma Proving Grounds/Luke-Williams Bombing and Gunnery Range (FN-TR-3, 1975c). This report, with its accompanying large graphics, represents the most recent and comprehensive compilation of available data on Lechuguilla Desert up to 1975. In addition, key references used in FN-TR-15 and data compiled

since 1975 were specifically obtained, reviewed, and evaluated. All cited references are listed in the Bibliography

4.2.3 AERIAL PHOTOGRAPHY INTERPRETATION

Aerial photography interpretation (photogeology) was a primary technique utilized in the engineering geology investigation. Photogeologic interpretation and mapping of Lechuguilla Desert were completed in the two week period from 2 May to 13 May. Exposed geologic units were delineated on overlays over color stereo aerial photos (scale 1:24,000). Interpretations were supplemented by examining color Infra-Red (IR) stereo aerial photos (scale 1:24,000), a semi-controlled black and white photomosaic (scale 1:62,500), existing black and white stereo aerial photographs (scale 1:62,500), and existing orthophoto maps (scale 1:24,000).

Emphasis was placed on delineating boundaries of rock and surficial basin-fill units. General structure, lithology, and erosional characteristics of rock units as well as areas of potential hazard or difficult construction observed were recorded.

The results of the investigation were used to select geologic field check stations, boring, trench, and seismic line locations on representative surficial geologic units and are presented on Drawings 1, 2, and B-1.

4.2.4 FIELD INVESTIGATION

The field investigation included field checking photogeologic

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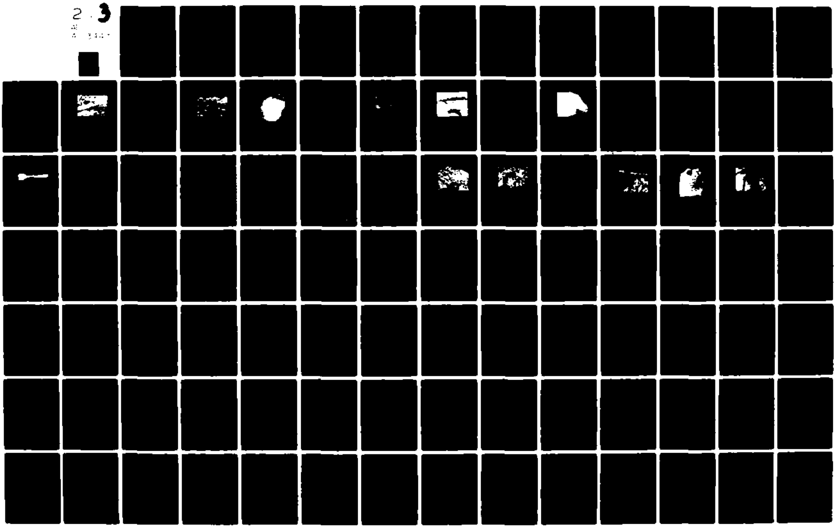

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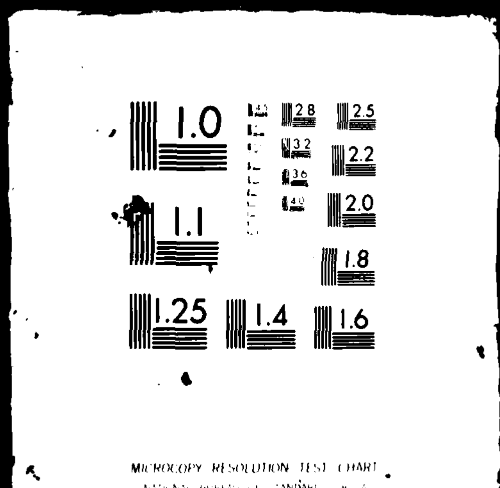


mapping and recording on aerial photographs direct observations of geologic and hydrologic conditions (Section 4.1). Generally, the field activities were concentrated near the Valley periphery, an area of complex geological relationships. These activities included delineation of the rock/basin-fill contact, definition of colluvium and alluvial fan deposits, boulder fields, and features that may be related to structure in the rock areas (e.g., projections of faults). In addition, actual surface and subsurface exploration activity locations, such as field stations, borings, trenches, and seismic lines, were located on the aerial photos during the field investigation (Drawing 1; B-1). Microrelief and slope of selected basin-fill units were measured using an Abney level and stadia rod. Extensive portions of the central Valley, predominantly covered with geologically less complex younger alluvial fans (Section 4.4.2), required less detailed field checking.

Environmental constraints required that a two-man team field check the northeast portion of Lechuguilla Desert from 24 April to 28 April 1977, while the second two-man team completed the field examination of Mohawk-Tule Valley. Field checking of Lechuguilla Desert utilizing two teams resumed on 16 May and was completed on 11 June. In addition, a two-man field team evaluated the flooding potential in Lechuguilla Desert on 17 and 18 August 1977, following heavy rainfall associated with Tropical Storm Doreen (Section 4.7.1.6).

The following field data sheets were utilized to facilitate recording of all data:

- Soil Properties Data Sheet
- Soil and Caliche Profile Data Sheet
- Surface Morphology Data Sheet
- Rock Conditions and Material Resources Data Sheet
- Geologic Hazards Data Sheet
- Stream Gradient and Microrelief Profile Data Sheet

Procedures are contained in Appendix E of FN-TR-18. All data are presented in Summary Tables 5 and B-1.

Data obtained from photogeologic mapping and subsequent field checking are presented on Drawing 2 and Figures B-1 through B-18. Supplemental to the field mapping, data obtained from the subsurface investigations (borings and trenches) were characterized from an engineering geology standpoint. This included observing the materials encountered, recording features of geologic significance, and evaluating boring and trench logs prepared by the engineering staff, and downhole geophysical logs of selected borings. Resulting geologic data were integrated into and presented on the logs of borings and trenches (Section 5.2.2, Appendix C).

4.2.5 DATA COMPILATION

Compilation of recorded field data was initiated immediately and continued throughout the field investigation. Observed field geologic data recorded on aerial photographs were transferred daily to 1:24,000 scale orthophoto overlays. Microrelief traverses were performed in conjunction with the field investigation and profiles were plotted from the recorded data.

All data sheets were systematically filed by station number for easy reference.

Summaries of engineering properties and the geologic characterizations of subsurface data observed in the field were compiled as the field program progressed. Upon completion of the field program, and as laboratory analyses of samples were completed, summary sheets were compiled and utilized in preparing final boring and trench logs. Laboratory test data superceded field observations where appropriate. At the completion of the field investigation tabulation, additional analyses, and the final compilations and summaries were prepared at the Long Beach office (Tables 5 and 6; Tables B-1, B-2, and B-3).

4.3 TOPOGRAPHIC CONDITIONS

Lechuguilla Desert topography ranges from the steep (commonly > 100% slope) and rugged flanks of the Gila and Copper Mountains to the relatively flat (< 1% slope) alluvial fans in the central and northern Valley (Drawing 2). Elevations range from 376 feet (115 m) above mean sea level (MSL) at the northern border of the Valley to 1192 feet (363 m) in the Wellton Hills, 2888 feet (880 m) in the Copper Mountains; and in the Gila Mountains, Sheep Mountain has an elevation of 3156 feet (962 m). The maximum overall relief of 2780 feet represents elevation differences between Sheep Mountain and the northern lowlands area. Maximum valley relief is 1025 feet (312 m) from the highest mapped alluvium (Cipriano Pass) to Northern Coyote Wash.

Coyote Wash defines the axis of the Valley, separating the alluvial plains extending from the Copper and Gila Mountains (Drawing 2). The gradient of Coyote Wash varies south to north from 0.5 to 0.8 percent. Microrelief profiles across typical basin-fills units are included in Appendix B (Figures B-8 through B-17).

Principal topographic features of Lechuguilla Desert, other than the perimeter mountain ranges and the Wellton Hills, are the alluvial fans (Drawing 2). Slopes of these fans, extending from the base of the Gila and Copper Mountains and the Wellton Hills, vary from less than one percent on the younger alluvial fan (A5yf) surfaces found throughout the central basin to less than ten percent on intermediate alluvial fans (A5i), to vertical

on highly dissected older alluvial fans (A5Oc) found only in the extreme northwest corner of the Valley.

In general, slopes of alluvial fan surfaces do not exceed five percent, except for those observed within mountain reentrants. Slopes on intermediate to younger age fans do not differ greatly despite their relative ages; the average range on the intermediate fans is 2.4 to 4.1 percent whereas the average range on younger and intermediate-younger fans is 1.1 to 1.5 percent, (Table 5; Section 4.4.8). Maximum relief between fan surfaces and the intervening drainages on younger alluvial fans is less than three feet (1 m) throughout most of the central basin. Microrelief within intermediate (A5i) and intermediate-younger fans (A5iy) exposed in the central basin is generally similar to younger fans, but because of slightly more incised streams, total relief may be three to five feet (one to 1.5 m). In general, drainage density decreases whereas total relief on these fans increases toward mountain fronts to a maximum of ten to 20 feet (3 to 6 m) on intermediate fans adjacent to rock. Topography is characterized by deeply incised, steep-walled, flat-bottomed channels near fan apices. Gradients of streams incised into these intermediate age, elevated alluvial fans are slightly less than the slope of the surfaces, whereas stream gradients and surface slopes are nearly identical on younger, topographically lower fans in the central basin.

Relief on the older fans (A5oc) in the northwest corner of the Valley is much greater. Advanced erosion has formed steep-

walled V-shaped drainages with flat bottoms up to 440 feet (134 m) wide and 130 feet (40 m) deep. Gradients of streams originating in the Gila Mountains and traversing these older deposits range from two to three percent, whereas streams originating in the deposits may have gradients of up to 90 percent in headwater areas.

In the southern portion of the Valley, alluvium-filled passes connect Lechuguilla Desert to Mohawk-Tule Valley on the east and Yuma Desert on the west. Elevations of these passes are approximately 909 feet (277 m) and approximately 980 feet (199 m), respectively (Drawing 2).

4.4 SURFICIAL BASIN-FILL UNITS

4.4.1 GENERAL

Alluvial fan deposits are the most abundant type of surficial basin-fill units exposed in the Valley and are present to construction excavation depths (20 to 30 feet; 6 to 9 m) over at least 83 percent of Lechuguilla Desert (Drawing 2). These deposits extend to various depths below the construction zone and are in turn underlain by older basin-fill deposits. Data obtained do not clearly distinguish these conditions, therefore, the following discussions of alluvial fan units are limited to those exposed and/or those extending through the construction zone.

Photogeologic and field mapping results indicate there are four primary relative ages of alluvial fans exposed in the Valley; younger (A5y), intermediate-younger (A5iy), intermediate (A5i), and older (A5o). Generally, the younger fans form a thin veneer over most of the central basin, while the intermediate-younger, intermediate, and older fans are exposed near the basin perimeter (Drawing 2).

Alluvial deposits of southwestern Arizona and southeastern California have been dated by soil profile development calibrated with radiometric and paleomagnetic age dates (San Diego Gas and Electric Company, 1976). Based on similar climatic and tectonic setting, preliminary correlations may be made with the alluvial fans of Lechuguilla Desert. Younger alluvial fan units as mapped in Lechuguilla Desert correlate in terms of soil development and surface morphology to active fan deposits dated

at less than 15,000 years before the present (BP). Intermediate-younger and intermediate alluvial fan deposits roughly correlate to lower and middle-level intermediate (Q_3) deposits dated at 15,000 to 100,000 years BP and middle level deposits at 100,000 to 200,000 years BP respectively. Parts of intermediate level fans in northwestern Lechuguilla Desert may also correlate to upper level intermediate (Q_3) fans dated at mid-to-upper-Pleistocene (200,000 to greater than 500,000 years BP). Older alluvial fans in northwestern Lechuguilla Desert are correlative with high level fans (Q_4) greater than 500,000 and perhaps greater than two million years BP.

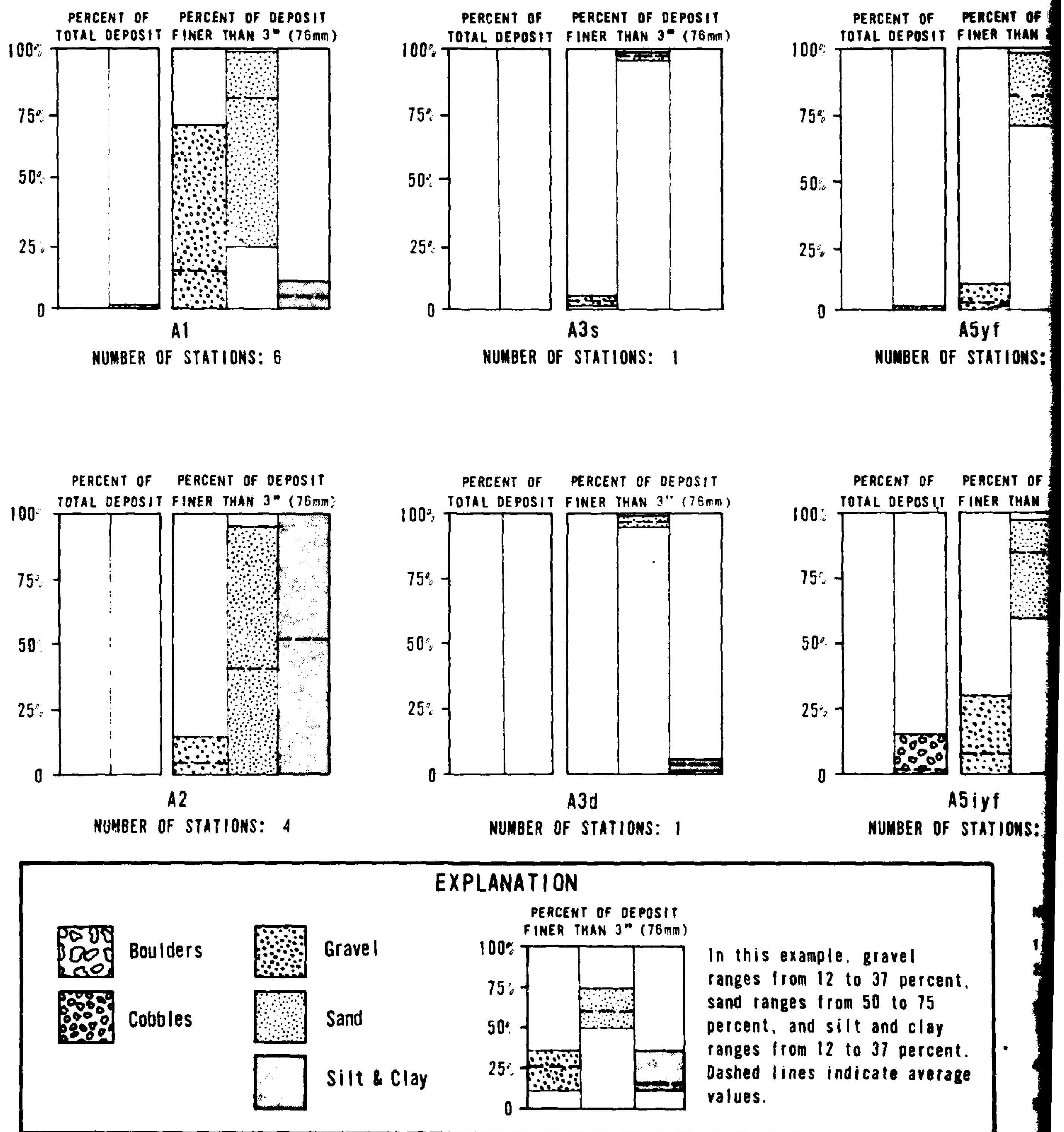
Other basin-fill units in Lechuguilla Desert are less extensive and less diverse. Eolian deposits, occurring either as dunes (A3d) or sheet sand (A3s), are not areally extensive and are stabilized. Stream channel deposits (A1) are also limited in areal extent and generally contained within alluvial fans. They are not specifically delineated except in major channels where properties are distinct from the surrounding basin-fill deposits (Drawing 2). Colluvium occurs intermittently along the base of steep slopes as thin wedge or prism shaped deposits.

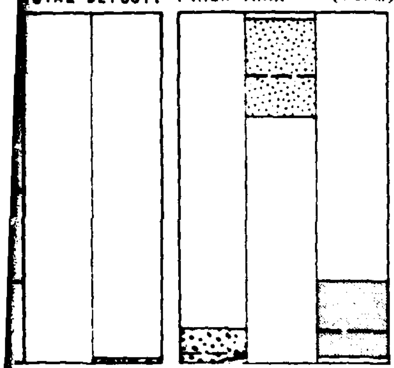
Data sheets were completed at 188 field stations in Lechuguilla Desert (see Appendix E, FN-TR-18, for procedures and data sheets). Physical and soil engineering properties, surface soil development, and surface morphology data were compiled in tabular form and are presented on Table 5. All data are based on field determinations (USCS classification, particle size distribution, etc.) and reflect the character of surficial basin-fill units of

Lechuguilla Desert. Block diagrams illustrating the general configurations and relationships of basin-fill units were shown previously in Figures 4 and 5 (Section 2.1.3). Histograms of physical properties determined from field observations of surficial basin-fill units are presented in Figure 8. Geologic cross sections illustrating specific relationships of exposed and near-surface geologic units are shown in Figures B-1 through B-6 (Appendix B). Geological characterization of shallow trench excavations and borings are incorporated into Soils Engineering Logs, and are presented in Appendix C.

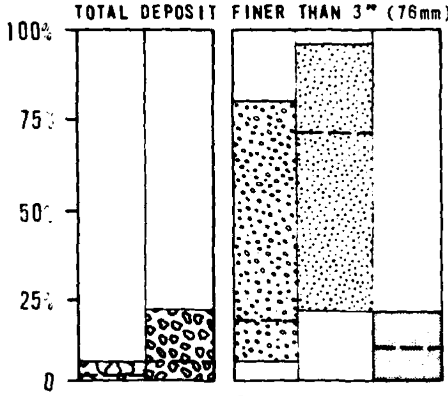
4.4.2 ALLUVIAL UNITS

Four distinct levels and relative ages of alluvial fans have been differentiated (Drawing 2) and are designated: A5y (younger), A5iy (intermediate-younger), A5i (intermediate), and A5o (older). Each alluvial fan unit consists of poorly sorted, heterogeneous to poorly stratified mixtures of boulders, cobbles, gravel, sand, and fines. The concentration of boulder-cobble-gravel mixtures is greater near fan apices in steep mountain canyons, grading into mixtures of gravel, sand, and fines toward central basin areas. Areas of predominantly finer-grained deposits less than three inches (76 mm) in diameter (clay, silt, sand, gravel) with no boulders have been designated by the letter f (e.g., A5yf, A5iyf, A5if). Alluvial fan deposits containing boulders have been designated by the letter c (e.g., A5iyc, A5ic, A5oc). In general these deposits also contain significant amounts of material larger than three inches (average percent = 25, Figure 6). The presence of boulder is the overriding criteria to aid in

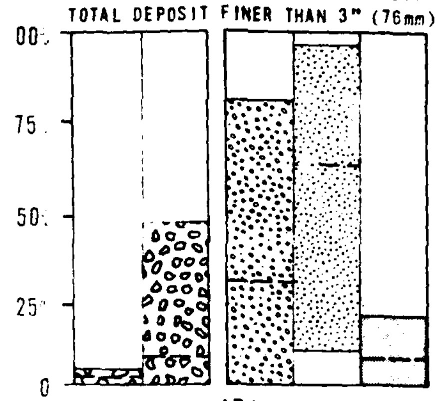

PERCENT OF TOTAL DEPOSIT
PERCENT OF DEPOSIT FINER THAN 3" (76mm)
100%
75%
50%
25%
0
A1
NUMBER OF STATIONS: 6
A3s
NUMBER OF STATIONS: 1
A5yf
NUMBER OF STATIONS:
A2
NUMBER OF STATIONS: 4
A3d
NUMBER OF STATIONS: 1
A5iyf
NUMBER OF STATIONS:
EXPLANATION
Boulders
Cobbles
Gravel
Sand
Silt & Clay
In this example, gravel ranges from 12 to 37 percent, sand ranges from 50 to 75 percent, and silt and clay ranges from 12 to 37 percent. Dashed lines indicate average values.



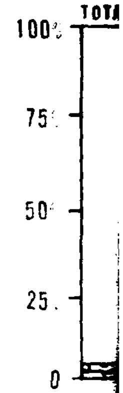
A5yf
NUMBER OF STATIONS: 24

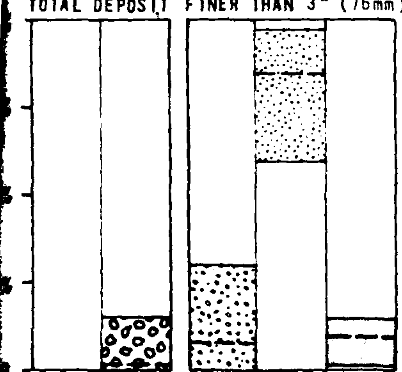


A5iy
NUMBER OF STATIONS: 12

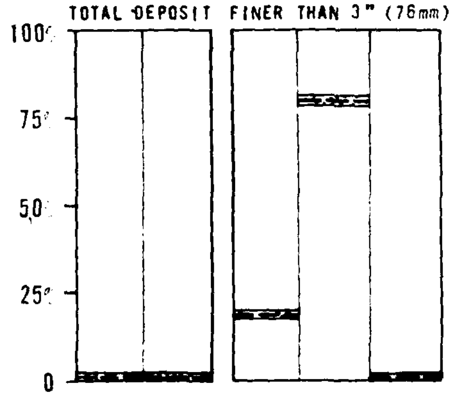


A5i
NUMBER OF STATIONS: 14

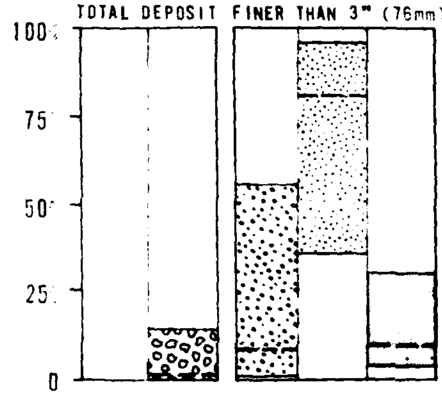




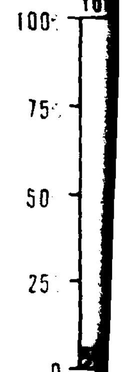
A5iyf
NUMBER OF STATIONS: 18



A5iyc
NUMBER OF STATIONS: 1



A5if
NUMBER OF STATIONS: 29



ple, gravel
12 to 37 percent,
from 50 to 75
silt and clay
12 to 37 percent.
indicate average

NOTES:

1. All values are derived from field classification only.
2. Percent range of boulders and cobbles is a volume estimate based on the entire sample.
3. Percent range of gravel, sand, silt and clay is a volume estimate based on fraction of sample finer than 3".
4. See Table 1 for additional physical and soil engineering properties.
5. Where data are based on one station, range indicated represents accuracy (±5%) inherent in all field data shown.

GRA

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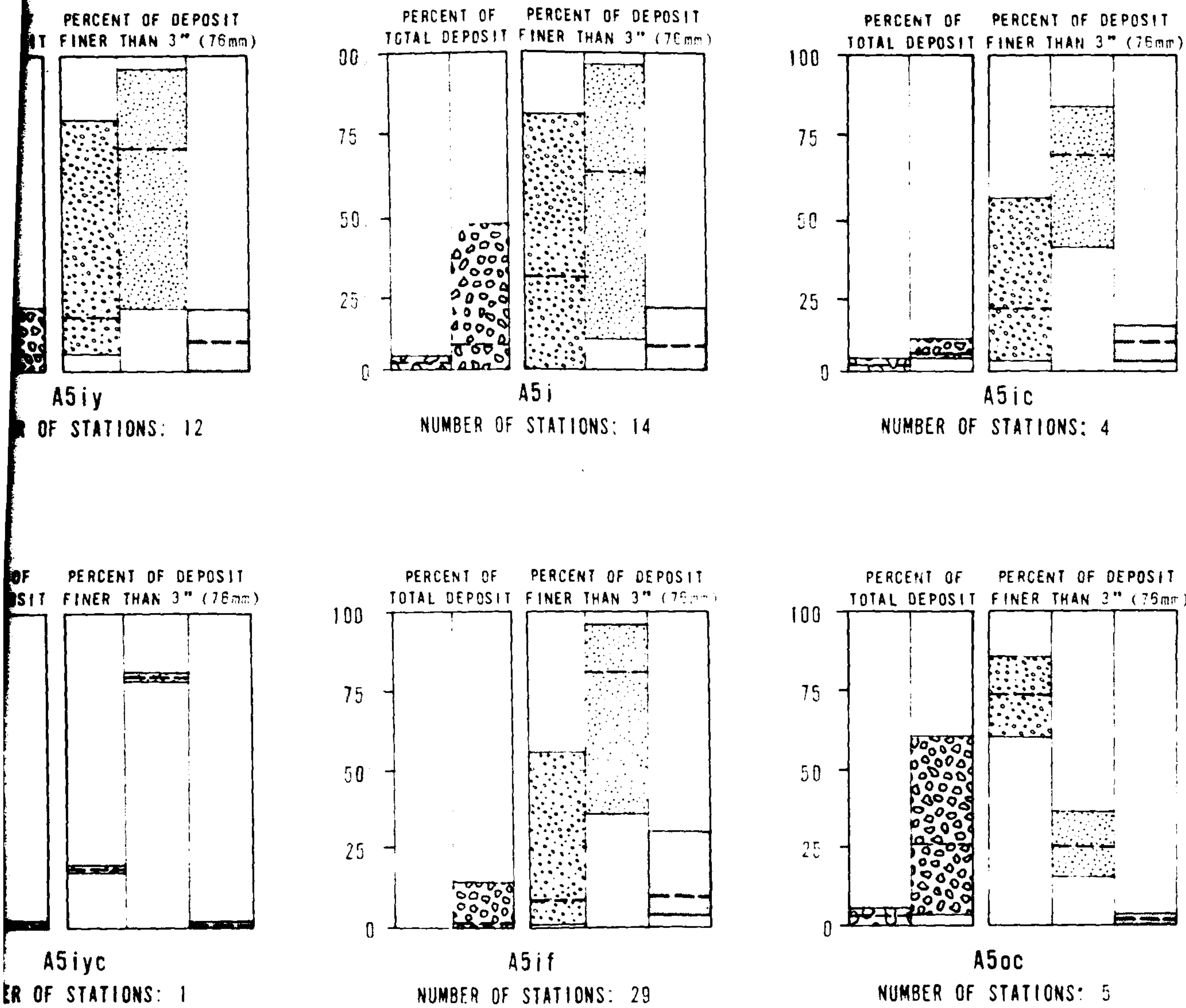

field classification only
d cobbles is a volume
sample
d, silt and clay is a
ction of sample finer

hysical and soil engineer-

tation, range indicated
nherent in all field data

GRAIN SIZE DISTRIBUTION HISTOGRAMS
FIELD CLASSIFICATION
LECHUGUILLA DESERT, ARIZONA

MX SITING INVESTIGATION DEPARTMENT OF THE AIR FORCE - SAMSO	FIGURE 8

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2

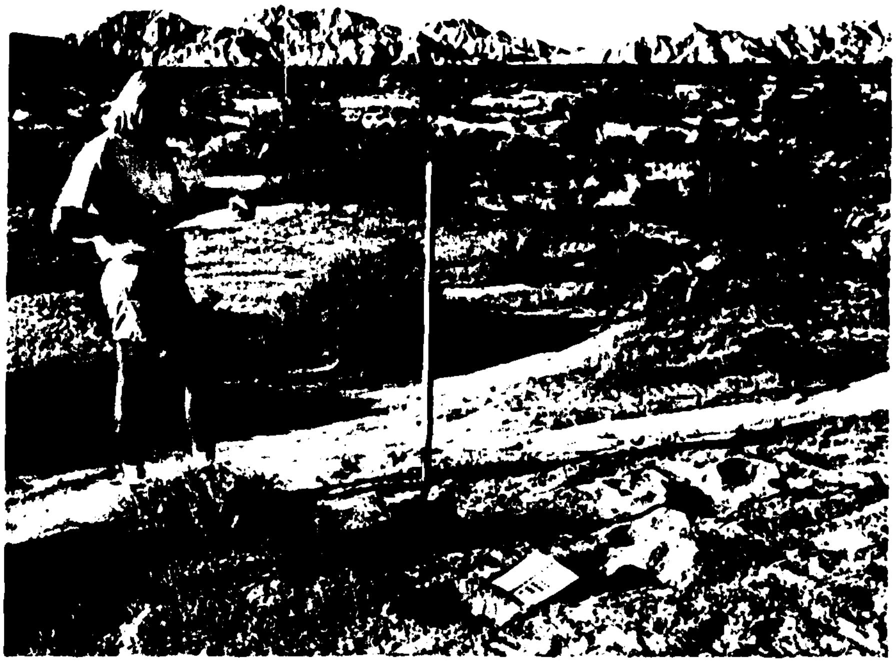
3

the prediction of such occurrences in areas where exposures are limited. Alluvial fan units which contain both coarser and finer materal, or fans for which insufficient data were obtained to allow differentiation are given no grain size designation. A general description of each alluvial fan unit is given below.

4.4.2.1 Younger Alluvial Fans (A5y, A5yf)

Younger alluvial fans are the most areally exposed deposits, covering 84 nm^2 (288 km^2) or 51 percent of the Valley (Drawing 2). (Drawing 2). These fans occur principally in the central basin and are usually separated from surrounding rock areas by intermediate and intermediate-younger fans (Figure 9).

Sediment derived from the mountains and their surrounding colluvial areas or from the dissection of higher intermediate and intermediate-younger alluvial fans are transported as stream channel deposits across younger alluvial fans during periods of high intensity rainfall. The basin is not actively aggrading at present and the younger alluvial fan deposits are generally less than five feet (1.5 m) thick. Areas where the depth of this unit is known from nearby exposures, borings, trenches, stream cuts, or test pits to be less than five feet (1.5 m) thick are shown on Drawing 2 with a parenthetical designation, i.e., A5y (A5i). The unit in parenthesis underlies the younger fan unit. Generally, isolated outcrops of the buried alluvial fan unit occur throughout areas adjacent to this parenthetical designation. The only younger alluvial fan deposits which are not finer-grained are transported as stream channel deposits in northwestern Lechuguilla Desert on the floors of major entrenched



Finer-grained younger alluvial fan (A5yf; Section 4.4.2). Detrital material is transported across fan surface in braided stream channels as shown in foreground. View is south; Gila Mountains in background.

YOUNGER ALLUVIAL FAN PHOTOGRAPH
LECHUGUILLA DESERT, ARIZONA

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FIGURE 9

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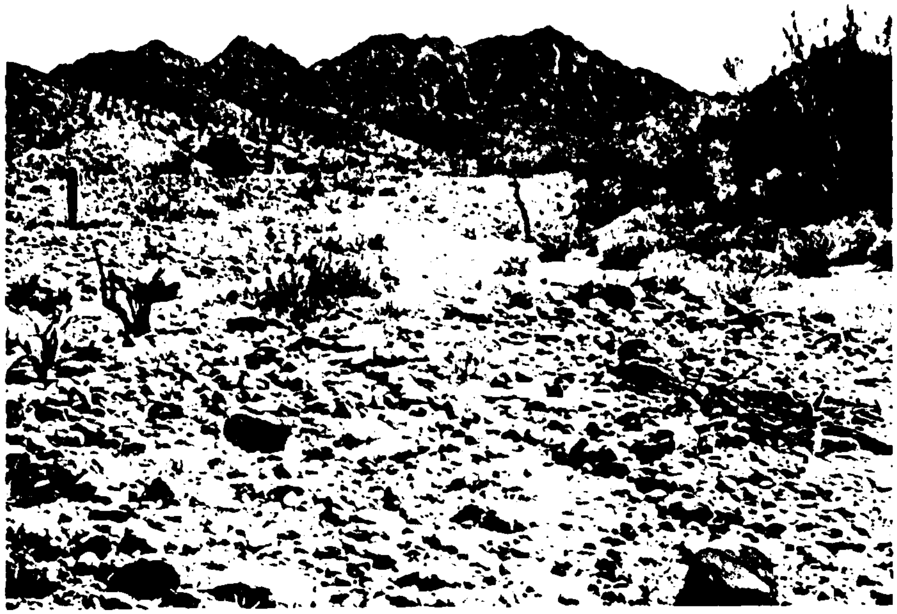
streams and are depicted as mixed deposits (A1/A5y, Sections 4.3 and 4.4.7).

Some sediment transport occurs over surfaces of younger alluvial fans during periods of high intensity rainfall but it is generally confined to shallow channels. Channel depth and local microrelief of these younger alluvial fan surfaces generally do not exceed two feet (0.5 m, Microrelief Profiles B-8 through B-17). Surface slopes vary from a maximum of 1.6 percent near mountain fronts to less than one percent in central basin areas. Younger alluvial fans commonly exhibit no desert pavement to poorly developed desert pavement, with no patina or B-horizon, and are uncemented to weakly cemented (Table 5). Carbonate is finely disseminated throughout the deposit with no discrete caliche horizons. Soil color is reddish yellow to brownish yellow (7.5YR to 10YR range of the Munsell Color Classification).

4.4.2.2 Intermediate-Younger Alluvial Fans (A5iy, A5iyf, A5iyc)

Intermediate-younger alluvial fans (Figure 10) cover 14 nm^2 (48 km^2) or nine percent of the Valley, occurring principally near the mountain fronts but also as isolated remnants throughout the Valley (Drawing 2). Observed thicknesses of this deposit are generally less than ten feet (3 m). Intermediate-younger fans are of a relative geologic age between younger and intermediate fan units and exhibit properties of both (Figure 11).

Surfaces of these fans are inactive in terms of modern sediment transport although ample evidence for past activity remains. Bar and channel topography, particularly on surfaces near the mountain



Coarser-grained intermediate-younger alluvial fan surface (A5iyc; Section 4.4.2.2) in northwestern Lechuguilla Desert. Note bouldery, bar and channel topography. View is south toward older alluvial fans (A5o; Section 4.4.2.4). and Gila Mountains, in background. Twelve inch (30m) boulder in foreground provides scale.

INTERMEDIATE-YOUNGER ALLUVIAL FAN PHOTOGRAPH
LECHUGUILLA DESERT, ARIZONA

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FIGURE 10

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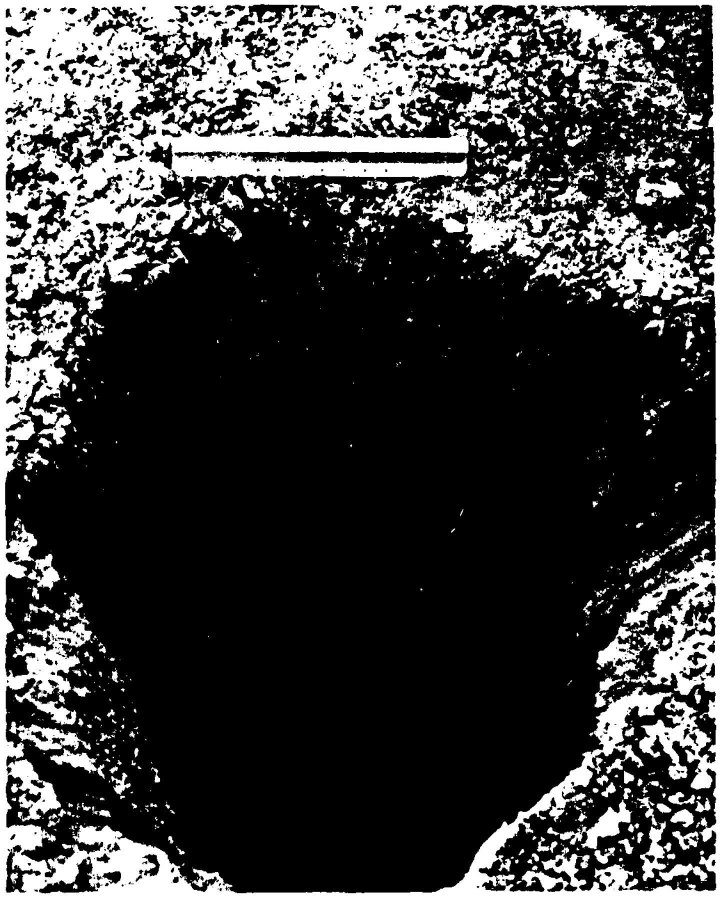

Hand-dug test pit located south of Wellton Hills just east of Coyote Wash in finer-grained intermediate-younger alluvial fan (A5iyf; section 4.4.2.3), demonstrating typical moderately developed desert pavement and lack of patina. Rule provides scale; 6 inches (15cm).

PHOTOGRAPH OF HAND-DUG TEST PIT LOCATED IN INTERMEDIATE-YOUNGER ALLUVIAL FAN LECHUGUILLA DESERT, ARIZONA	
MX SITING INVESTIGATION DEPARTMENT OF THE AIR FORCE SAMSO	FIGURE 11

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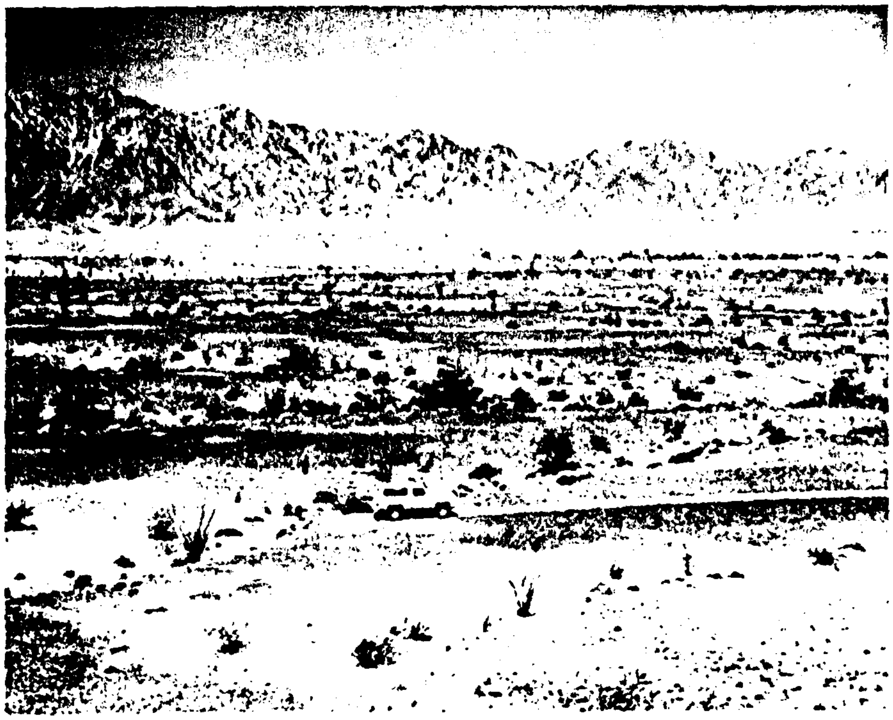
fronts, is well developed with average relief of three to 4.5 feet (90 cm to 1.4 m) (Appendix Figures B-8 through B-17). Streams are generally incised to depths of five feet (1.5 m) into these fans adjacent to the mountain front, decreasing to less than two feet (60 cm) at the furthest basin-ward extent. Surface slopes range from five to less than one percent.

Soil profiles (pedogenic) are present but poorly developed. Pavement and patina on these uncemented to weakly cemented deposits may be absent to well-developed. No distinct B-horizon is present although soil color ranges from reddish brown to brownish yellow (5YR to 10YR) with a predominant reddish yellow (7.5YR) hue and are uncemented to weakly cemented (Figure 12). Caliche development in intermediate-younger alluvial fans varies from no apparent carbonate to Stage I and occasional Stage II profiles with carbonate filaments, nodules, and pebble coatings.

4.4.2.3 Intermediate Alluvial Fans (A5i, A5if, A5ic)

Intermediate alluvial fan deposits cover 15 nm^2 (51 km^2) or nine percent of the Valley and generally occur as isolated outcrops in the central basin (Drawing 2). This unit is present uniformly in the subsurface throughout the Valley underlying younger and intermediate-younger deposits generally within five feet (1.5 m) of the surface (Figure 13). It is the most volumetrically extensive surficial geologic unit within the construction zone.



Well developed desert pavement and patina of intermediate alluvial fan surface (A5i; Section 4.4.2.3). Smooth sparsely vegetated surface is undergoing dissection by modern drainages eroding headward near Gila Mountains (background) and flowing to the north. View west across older alluvial fans (A5o; Section 4.4.2.4).

INTERMEDIATE ALLUVIAL FAN PHOTOGRAPH
LECHUGUILLA DESERT, ARIZONA

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FIGURE 12

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Stream cut in northern Lechuguilla Desert, showing 3 feet (1m) of weakly cemented intermediate-younger alluvial fan (A5iy); Section 4.4.2.2) overlying 10 feet (3m) of moderately to strongly cemented intermediate alluvial fan (A5i; Section 4.4.2.3). Note stratification in underlying exposure, and stream channel deposit (A1; Section 4.4.5). View is south.

PHOTOGRAPH OF STREAM CUT EXPOSING INTERMEDIATE-YOUNGER AND INTERMEDIATE ALLUVIAL FAN LECHUGUILLA DESERT, ARIZONA

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FIGURE 13

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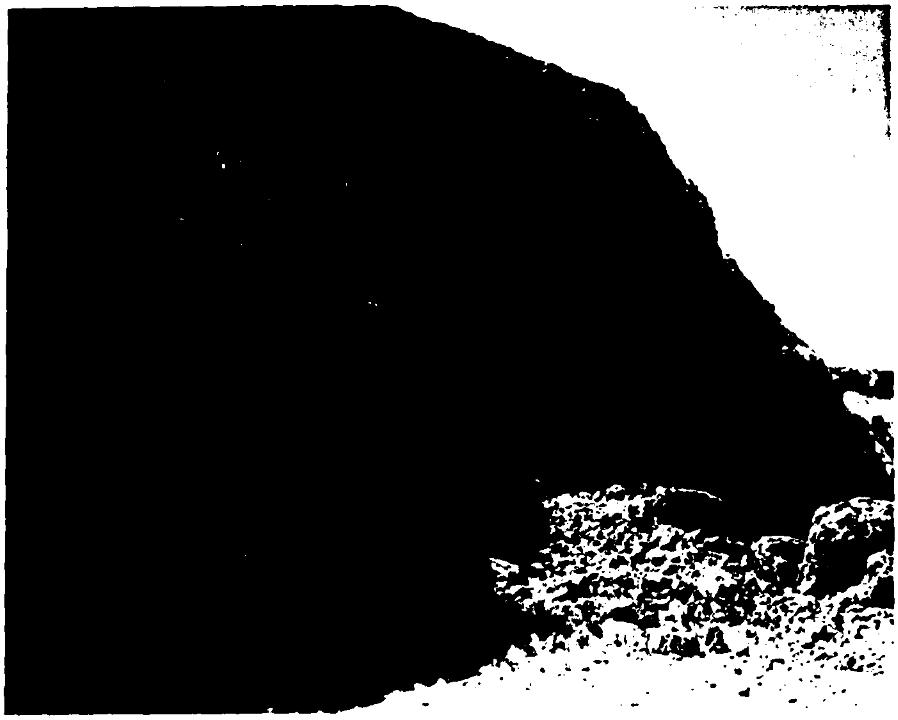
Exposed intermediate alluvial fans (A5i) are generally elevated above intermediate-younger (A5iy) and younger (A5y) levels and are subject to erosion (Figure 14). Microrelief (Figures B-8 through B-17) is similar to intermediate-younger alluvial fans (average 3.5 feet; 1.1 m). Incision is greatest in northwestern Lechuguilla Desert (average 13 feet; 4 m) but decreases to an average of three feet (90 cm) throughout the remainder of the Valley. Surface slopes are generally steeper than relatively younger fan units; ranging from 4.1 percent on coarser-grained intermediate fan surfaces to 2.4 percent on finer-grained intermediate fan surfaces.

The weakly to strongly cemented intermediate alluvial fan units commonly exhibit relatively well developed soil profiles with poorly to well pavemented surfaces and with patina absent to well developed (Table 5). In the subsurface, they are characterized generally by combinations of well-developed reddish B-horizons and Stage II caliche development with filaments, flakes, abundant nodules, continuous pebble coatings and some interpebble fillings (Appendix E FN-TR-18). Color is predominantly reddish brown to reddish yellow (5YR to 7.5YR).

4.4.2.4 Older Alluvial Fans (A5oc)

Older alluvial fan deposits (A5oc-Drawing 2) cover three nm^2 (10 km^2) or two percent of the Valley. Outcrops are confined to the extreme northwestern Lechuguilla Desert adjacent to the Gila Mountain front (Drawing 2). Exposed sections of these deposits exceed 100 feet (30 m) and actual thicknesses are



Terrace deposit (A2; Section 4.4.3) capped by intermediate alluvial fan unit (A5i; Section 4.4.4). Thirty-five-foot (11m) high stream cut exposes 10 feet (3m) of cobbly intermediate alluvial fan overlying 25 feet of interbedded sand and silt (light layers) and clays (dark layers). View to west of extreme northwest portion of Lechuguilla Desert.

PHOTOGRAPH OF STREAM CUT EXPOSING INTERMEDIATE ALLUVIAL FAN AND TERRACE DEPOSIT LECHUGUILLA DESERT, ARIZONA	
MX SITING INVESTIGATION DEPARTMENT OF THE AIR FORCE SAMSO	FIGURE 14
FUGRO NATIONAL, INC.	

probably much more. Only coarser-grained older alluvial fan units (A5oc) were identified at the surface.

Older alluvial fans are topographically higher than all other fan units exposed in Lechuguilla Desert. Generally, they are highly dissected (average depth of incision 55 feet; 17 m) and no original fan surfaces remain. They consist of narrow ridges flanked by smooth, steep slopes commonly undercut by modern streams to form near-vertical to vertical exposures.

Due to the advanced stage of dissection and erosion, soil profiles (pedogenic) are not well developed on older alluvial fan units. Pavement and patina are well developed only along ridges where a narrow, flat drainage divide exists. The deposits are moderately to strongly cemented with Stage II to III carbonate present throughout. Color of matrix materials is predominantly yellow to brownish yellow (7.5 YR-10YR) but is somewhat masked due to the predominance of coarser rock debris.

4.4.3 TERRACE

Well stratified terrace deposits (A2) of sand, silt, and clay crop out locally in the extreme northwestern corner of Lechuguilla Desert (Figure 14). They cover less than one nm^2 (less than 0.1 percent areally), are overlain by intermediate alluvial fan units, and have been deeply incised (30 to 40 feet; 9 to 12 m) by modern streams. They appear from reconnaissance mapping to either interfinger with or overlie older alluvial fan units, placing them in an age range of greater than 200,000 years BP but probably still Plio-Pleistocene in age (Section 4.4.1).

These deposits have been mapped north of the LBGR boundary by Olmstead and others (1973) as being of mixed origin and are described as intertonguing deposits of locally derived alluvium and old deposits of the Gila River. They are described as consisting of a zone of silt and fine sand which grades into well sorted river sand toward the Gila River and into poorly sorted gravelly deposits toward the mountains. As exposed in the Valley they are generally similar; consisting of horizontal, well stratified interbeds of well sorted clay, silt, and fine sand, with interbeds of clay, silt, sand, and gravelly sand toward the Gila Mountains. Their extent in the subsurface is unknown, as they are exposed only locally in stream cuts and exploration trench LD-T-1, and boring LD-A-1 in northeastern Lechuguilla Desert between the Wellton Hills and Baker Tanks (Drawing 2).

4.4.4 EOLIAN

Wind-blown sheet sand (A3s) and isolated sand dunes (A3d) cover 0.1 nm^2 (0.3 km^2) and less than 0.1 nm^2 (0.3 km^2) of the Valley, respectively (Drawing 2). A series of stabilized transverse and longitudinal dunes (A3d) occurs in the southeastern corner of Lechuguilla Desert in the vicinity of the pass into Mohawk-Tule Valley. These dunes were derived from Coyote Wash and its tributaries as southwesterly winds were funneled in a north-northeasterly direction through this alluvial pass into adjoining Mohawk-Tule Valley. Sheet sands (A3s) occur in northern Lechuguilla Desert at the base of the Wellton Hills east of Coyote Wash. These sands are well stabilized and are covered

by a gravel and cobble lag of alluvial material washed from the adjacent Wellton Hills. Thickness of the eolian deposits is generally less than ten feet (3 m).

Grain-size distribution of eolian deposits is approximately 95 percent sand with zero to less than five percent silt. Gravel-size caliche concretions and over bank deposits are locally present on the surface, but comprise less than one percent of the total deposit. Eolian deposits are generally very loose to loose, although some of the more stabilized dunes become medium dense about one foot (30 cm) below the surface. For additional soil property data, see Tables 5 and B-1.

No soil horizons (pedogenic) were observed in the eolian deposits and desert pavement and patina are not developed on their surfaces. Locally, secondary carbonate accumulation in the form of nodular caliche has developed in older stabilized materials.

4.4.5 CHANNEL

Stream channel deposits are present on and adjacent to alluvial fan surfaces throughout the Valley, but are not generally depictable at the map presentation scale (1:62,500). Coyote Wash and several incised channels near the mountains occupy 0.5 nm^2 (1.5 km^2) or less than one percent of the Valley (Drawing 2). Many smaller channels and washes are included within alluvial fan units (Section 2.3.1). Buried channel deposits are present at various depths throughout the Valley. Secondary washes are continually filling and shifting laterally to form anastomosing channel systems.

Channel configurations within alluvial fans are depicted on Microrelief Profiles B-8 through B-16 which represent the surface morphology perpendicular to the slope direction. Stream gradients range from over four percent near the mountains to less than one percent in the central Valley. In general, incision is greatest (three to 25 feet; 1 to 8 m) near the mountains becoming shallower (less than one foot; 30 cm) toward the Valley axis.

Channel deposits vary in composition from sandy gravel with cobbles and boulders near mountain fronts to sand in the central Valley (Figure 15). Where mapped (Drawing 2), these deposits consist predominantly of sand (25 to over 95 percent) with minor amounts of gravel and silt.

Soil horizons, caliche, and pavemented surfaces are not present in surficial channel deposits due to active deposition and erosion cycles. Older buried channels are present within alluvial fans of all ages and exhibit cementation characteristics similar to those of the fan in which they are buried (Section 4.4.2). These older buried channels may contain boulders, cobbles and gravels, similar to those exposed at the present time.

4.4.6 COLLUVIUM

Colluvium consists of heterogeneous material deposited predominantly by mass wasting at the base of steep mountain slopes. In general these deposits of gravels, cobbles and boulders occur as thin discontinuous wedge shaped masses, less than 30 feet (9 m) thick and ranging from less than one hundred feet (less than 30 m) to a

Stream Channel deposit (A1; Section 4.4.5) composed of poorly-graded medium sand. in Coyote Wash in the central portion of Lechuguilla Desert. View is southeast with Copper Mountains in background. The deposits are approximately 150 feet (46m) wide in the center of the picture.

STREAM CHANNEL DEPOSIT PHOTOGRAPH
LECHUGUILLA DESERT, ARIZONA

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FIGURE 15

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few thousand feet (1 km) in lateral extent. They are more extensive at the base of mountains composed of metamorphic rock (northern Gila Mountains and Wellton Hills) than at the base of those composed of intrusive igneous rocks (southern Copper and southern Gila Mountains) or sedimentary rocks (Baker Peaks). This is due in part to a more rapid rate of weathering and in part to differing shedding characteristics of the igneous and sedimentary rocks which causes them to be broken into finer particles that are transported away from mountain fronts.

Patina has locally developed on colluvial deposits, however, their characteristic coarse nature (boulders, cobbles, and gravels) and occurrence on steep slopes characterized by erosion, downslope creep and lack of fines, tend to prevent the development of soil profiles.

Colluvium was specifically mapped and depicted on the 1:24,000 scale aerial photographs. However, due to its limited areal extent, it is combined with rock units on Drawing 2 at final presentation scale (1:62,500). Except for an exceptionally large deposit specifically indicated on Drawing 2 (northwestern Lechuguilla Desert), its presence is indicated by a dashed bedrock-alluvium contact.

4.4.7 MIXED

In areas where two or more deposits are intermixed and contacts are gradational or too complex to be delineated at map scale, a combined symbol is used on Drawing 2 consisting of the individual unit symbols separated by a slash. The predominant unit

(greater than 50 percent) is written first. For example, the combined symbol A1/A5y denotes channel deposits with local areas of young alluvium comprising less than 50 percent of the total area delineated.

Areas of mixed deposits in Lechuguilla Desert were limited to channel deposits and younger alluvial fan deposits (A1/A5y, A1/A5yf) associated with Coyote Wash and the unnamed major washes adjacent to older and intermediate alluvial fans in the northwest corner. These deposits occupy approximately seven nm^2 (25 km^2) or six percent of the Valley (Drawing 2). Because engineering properties, soil development and surface morphology of these deposits fall within the range of values observed for the A1 unit, they are combined with the A1 unit on Table 5.

4.4.8 AREAS OF SHALLOW ROCK

The occurrence of limited amounts of shallow rock less than 50 feet below ground surface is suspected in the northeast corner of Lechuguilla Desert. This is evidenced by geophysical data and isolated basinward rock outcrops in the Baker Peaks area (Drawing 2). Similar areas of possible shallow rock occur around the Wellton Hills and on the southern Copper Mountain front where low, isolated bedrock outliers are common. Areas of shallow rock exposed at the surface or in stream cuts are shown as a combined symbol, e.g., A5i(S) on Drawing 2.

ENGINEERING GEOLOGY UNIT	NUMBER OF FIELD STATIONS (APPENDIX B)	MATERIAL P				
		DESCRIPTIVE NAME(S)	USCS SYMBOL(S)	AREAL EXTENT (VALLEY)		MAX. GRAIN SIZE
				nm^2 (km^2)	PERCENT	
Stream Channel (A1)	6	Sand	SP	8 (27)[b]	5	Boulder
Terrace Deposits (A2)	4	Clay to Sand	CL to SP	0.1 (0.3)	0.1	Gravel
Eolian Sand, Sheet (A3s)	1	Fine Sand	SP	<0.1 (<0.3)	<0.1	Sand
Eolian Sand, Dune (A3d)	1	Sand	SP	0.1 (0.3)	0.1	Sand
Younger Alluvial Fan, Finer-Grained (A5yf)	24	Silty Sand	SM	84 (288)	51	Cobble
Intermediate-Younger Alluvial Fan (A5iy)	12	Silty Sand to Gravel	SM to GP	8 (27)	5	Boulder
Intermediate-Younger Alluvial Fan, Finer-Grained (A5iyf)	18	Sand to Silty Sand	SP-SM	6 (21)	4	Cobble
Intermediate-Younger Alluvial Fan, Coarser-Grained (A5iyc)	1	Gravelly Sand	SP	0.2 (0.7)	0.1	Boulder
Intermediate Alluvial Fan (A5i)	14	Sand and Gravel	SP-GP	10 (34)	6	Boulder
Intermediate Alluvial Fan, Finer-Grained (A5if)	29	Sand to Silty Sand	SP-SM	3 (10)	2	Cobble
Intermediate Alluvial Fan, Coarser-Grained (A5ic)	4	Gravelly Sand to Sandy Gravel	SP-GP	2 (7)	1	Boulder
Older Alluvial Fan, Coarser-Grained (A5oc)	5	Sandy Gravel with Cobbles	GP	3 (10)	2	Boulder

NOTES:
a) Data presented are derived from (TABLE B.1, Appendix B) and represent characteristic field classification properties.
b) This total includes areas of mixed deposits in which this unit predominates.
c) See also, Figure 8, Grain Size Distribution Histograms Field Classification.
d) Does not include values from northwestern Lechuguilla.
e) Slopes are extremely variable but range from 0-60% (A3d) and 0-80% (A5oc).

MATERIAL PROPERTIES[a]								SURFACE SOIL DEVELOP	
MAX. GRAIN SIZE	APPROXIMATE SIZE DISTRIBUTION (%)[c]				MUNSELL COLOR (HUE)	CEMENTATION		PAVEMENT/ PATINA	B HORIZON
	COBBLES AND BOULDERS (% OF TOTAL)	% OF FRACTION ≤ 3 INCHES (76 mm)							
		GRAVEL	SAND	FINES					
Boulder	0– <1	0–70	25–99	0–10	7.5YR–10YR	None–Weak		None/None	None
Gravel	0	0–15	0–95	0–100	5YR–10YR	Moderate		Well/Fair	None
Sand	0	< 5	> 95	0	10YR	Moderate		Poor/None	None
Sand	0	0	> 95	< 5	10YR	None		None/None	None
Cobble	0– <1	0–10	70–97	< 3–25	7.5YR–10YR	None–Weak		None/None	None
Boulder	0–2	< 5–80	20– >95	<1–20	7.5YR–10YR	Weak		Poor–Fair/ None–Poor	None
Cobble	0–15	<1 –30	60–98 +	< 1–15	7.5YR–10YR	None–Weak		Poor–Fair/ None	None
Boulder	—	20	80	<1	10YR	None–Weak		Poor/ Poor–None	None
Boulder	<1–50	< 1–80	10–95	0–20	5YR–10YR	Moderate–Strong		Well/ Fair–Well	Poor
Cobble	0–15	<1–60	35–95	< 5–30	5YR–7.5YR	Weak–Moderate		Fair–Well/ None–Poor	None–Poor
Boulder	6–10	< 5–55	40–85	< 5–15	5YR–10YR	Weak–Moderate		Fair–Well/ Fair–Well	None
Boulder	<1–60	60–85	15–35	0–5	7.5YR–10YR	Moderate–Strong		None–Well/ Poor–Well	None

		SURFACE SOIL DEVELOPMENT[a]			SURFACE MORPHOLOGY[a]		
MUNSELL COLOR (HUE)	CEMENTATION	PAVEMENT/ PATINA	B HORIZON	STAGE OF CALICHE (TABLE E-4)	SLOPE PERCENT	MAXIMUM MICRO-RELIEF FEET(METERS)	INCISION DEPTH/WIDTH FEET(METERS)
7.5YR-10YR	None-Weak	None/None	None	None	0.7	3.0 (0.9)	None
5YR-10YR	Moderate	Well/Fair	None	Locally II	Not Applicable	Not Applicable	Not Applicable
10YR	Moderate	Poor/None	None	I-II	No Data	No Data	5 (1.5)/
10YR	None	None/None	None	None	Not[e] Applicable	None	None
7.5YR-10YR	None-Weak	None/None	None	None-II	1.1	1.4 (0.4)	None
7.5YR-10YR	Weak	Poor-Fair/ None-Poor	None	None-II	1.5	3.0 (0.9)	5 (1.5)/ 47 (14.3)[d]
7.5YR-10YR	None-Weak	Poor-Fair/ None	None	None-II	1.3	2.9 (0.9)	3 (0.9)/ 40 (12.2)
10YR	None-Weak	Poor/ Poor-None	None	I	No Data	4.5 (1.4)	No Data
5YR-10YR	Moderate-Strong	Well/ Fair-Well	Poor	II	2.8	2.1 (0.6)	14 (4.3)/ 41 (12.4)
5YR-7.5YR	Weak-Moderate	Fair-Well/ None-Poor	None-Poor	II	2.4	2.4 (0.7)	3 (0.9)/ 16 (4.9)
5YR-10YR	Weak-Moderate	Fair-Well/ Fair-Well	None	II	4.1	6.0 (1.8)	13 (4.0)/ 110 (33.5)
7.5YR-10YR	Moderate-Strong	None-Well/ Poor-Well	None	II-III	Not[e] Applicable	None	55 (16.8)/ 231 (70.5)

SUMMARY OF PHYSICAL PROPERTIES, LECHUGUILLA DESERT, ARIZONA

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TABLE 5

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2 3

4.5 ROCK UNITS

4.5.1 GENERAL

For the purposes of this study, rock areas have been excluded from siting. They were investigated only as they directly affect siting considerations and the nature of basin-fill deposits derived from them. Rock units encountered are divided into the three major rock types; igneous, metamorphic, and sedimentary. Rock outcrop locations, descriptions, and distribution are presented in the following paragraphs and on Drawing 2. Complete descriptions of rock types are included in Appendix B.

4.5.2 IGNEOUS

Intrusive igneous (I1) rock within Lechuguilla Desert is mostly quartz-monzonite and comprises approximately 14 nm^2 (48 km^2), or 34 percent of the total exposed rock and nine percent of the total Valley (Figures 16 and 17). Its mineralogy is typical of the southern Basin and Range (Appendix B) and it crops out in the southern Copper and Gila Mountains (Drawing 2).

Extrusive igneous (I2) rocks do not crop out within the study area; however, flows of Pliocene-(?) basalt crop out in Raven Butte approximately one nm (1.9 km) south of the study area on the west side of the Valley. Other flow rock exists at depth below the alluvium within the study area as evidenced by basalt samples recovered from Borings LD-D-2 at a depth of 815 feet (250 m), and boring LD-C-5 at a depth of 255 feet (78 m); and anomalies recorded during the aeromagnetic-survey.

Jointed quartz monzonite (I1; Section 4.5.2) in the Gila Mountains exhibiting typical spheroidal weathering. Prominent joint set strikes N75W and dips 67N. Note small rockfall in right center. View to West.

IGNEOUS ROCK PHOTOGRAPH
LECHUGUILLA DESERT, ARIZONA

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FIGURE 16

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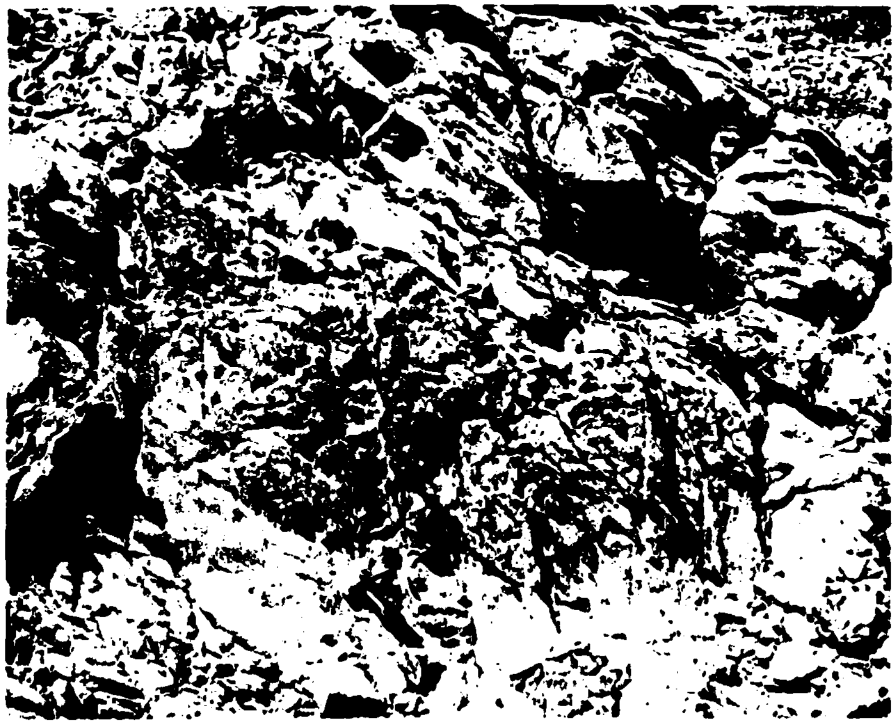

Jointed quartz monzonite (I1; Section 4.5.2) in the southern Copper Mountains. Predominant joint set strikes N20E and dips 80SE. Note hammer for scale.

IGNEOUS ROCK PHOTOGRAPH
LECHUGUILLA DESERT, ARIZONA

MX SITING INVESTIGATION DEPARTMENT OF THE AIR FORCE SAMSO	FIGURE 17

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4.5.3 METAMORPHIC

Gneissic and schistose metamorphic (M) rocks (Figure 18) have been identified within the study area and comprise approximately 19 nm^2 (65 km^2) or 46 percent of the total exposed rock and 12 percent of the total Valley. They occur in the central and northern Copper Mountains, Wellton Hills, and northern Gila Mountains (Drawing 2). The degree of detailed investigation necessary to define their complex field relationships was deemed unwarranted for this investigation, therefore, such distinctions were not made.

4.5.4 SEDIMENTARY

In Lechuguilla Desert, there are two main lithified sedimentary (S) rock types (granite-gneiss boulder conglomerate and arkosic sandstone) which comprise approximately eight nm^2 (27 km^2) or 20 percent of the total exposed rock and five percent of the total Valley (Figures 19 and 20). The most extensive exposures of sedimentary rock are in the extreme northern Copper Mountains (sandstone) and Baker Peaks area (conglomerate and sandstone). Two smaller outcrops of sedimentary rock (granite-gneiss boulder conglomerate) crop out in the central and northeastern portions of the Wellton Hills (Drawing 2).

4.5.5 ROCK CHARACTERISTICS

Physical properties that control the rate and character of the mechanical and chemical weathering of exposed rock surfaces are jointing, foliation, bedding, rock intrusions, and mineral composition. Table 6 summarizes the occurrence and nature of these properties as they exist in the three major rock units

Steeply dipping arkosic sandstone (S; Section 4.5.4) of the Baker Tanks in north-eastern Lechuguilla Desert. Bedding strikes generally N70W and dips 50SW. Larger clasts are rounded gneiss, quartz monzonite and granite cobbles and boulders in a red matrix of angular quartz, feldspar and mica grains. View to west.

SEDIMENTARY ROCK (ARKOSIC SANDSTONE) PHOTOGRAPH, BAKER PEAKS, LECHUGUILLA DESERT, ARIZONA

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FIGURE 18

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Boulder conglomerate (S; Section 4.5.4) in the low hills between Baker Peaks and Copper Mountains. Approximate strike of bedding N20W, dipping 65S. Larger clasts are rounded gneiss, granite and quartz monzonite in a matrix of light brown calcareous sand.

SEDIMENTARY ROCK (BOULDER CONGLOMERATE) PHOTOGRAPH, BAKER PEAKS, LECHUGUILLA DESERT, ARIZONA	
MX SITING INVESTIGATION DEPARTMENT OF THE AIR FORCE SAMSO	FIGURE 19

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Coarse-grained quartz biotite epidote gneiss (M; Section 4.5.3) in the Wellton Hills showing typical curving compositional banding, approximate strike of foliation N30W, dipping 25S. Rule provides scale; 6 inches (15cm).

METAMORPHIC ROCK (GNEISS) PHOTOGRAPH,
WELLTON HILLS,
LECHUGUILLA DESERT, ARIZONA

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FIGURE 20

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PHYSICAL PROPERTY	INTRUSIVE IGNEOUS (I1)	METAMORPHIC (M)	SEDIMENTARY (S)
JOINTS	Numerous-oriented along two major sets	Numerous-oriented along two major sets	Few
FOLIATION BEDDING	None	Well-developed	Conglomerate: *indistinct*. Sandstone: poorly to well defined.
PEGMATITIC DIKES VEINLETS (Secondary mineralization)	Some dikes	Numerous dikes	Some veinlets
PRIMARY MINERAL COMPOSITION	Quartz, feldspar, biotite	Quartz, feldspar, mica, amphibole, epidote, pyroxene	Quartz, feldspar, biotite

GENERAL ROCK CHARACTERISTICS
LECHUGUILLA DESERT, ARIZONA

MX SITING INVESTIGATION
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TABLE 6

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surrounding Lechuguilla Desert. Intrusive igneous rock, metamorphic rock, and the arkosic sandstone of the Baker Peaks area are the sources for greater than 90 percent of the sediments shed into the Valley (Drawing 2 and Appendix B). Localized variations of the three major rock units are not included in Table 6 or the following discussions. Tables B-2 and B-3 (Appendix B) contain a complete description of all planar structural elements observed and noted in rock in Lechuguilla Desert (Drawing 2).

Generally, jointing (Table B-2) and the abundance of feldspathic minerals produce large, spherical remnants which weather in place by granular disintegration and exfoliation and are the main contributors to weathering and shedding characteristics of intrusive igneous rocks in Lechuguilla Desert. Detritus produced by this spheroidal type of weathering is generally finer-grained (less than three inches; 76 mm) and forms most finer-grained colluvial and alluvial fan deposits (A5yf, A5iyf, A5if). Coarser-grained detritus (cobbles, boulders) is usually highly weathered and found near the source area (Drawing 2).

Metamorphic rocks shed slightly to moderately weathered blocky to platy cobbles and boulders defined by orientation and density of foliation and joints (Tables B-2, B-3). Near the source area, these clasts commonly form coarser-grained (cobbles, boulders) colluvium and alluvial fan deposits.

The arkosic sandstone of the Baker Peaks exhibits very little jointing and the bedding is massive to indistinct. Therefore, weathering characteristics are predominantly influenced by grain size and composition of the rock. Fragments shed are soft to hard, equidimensional sand- to boulder-sized particles. Because of their high feldspar content, the larger particles tend to disintegrate into smaller fragments near the source area. This finer-grained sedimentary rock detritus (less than three inches; 76 mm) commonly forms finer-grained alluvial fans (A5yf, A5if).

4.6 STRUCTURE

4.6.1 GENERAL

Principal emphasis of this section is on faults; in particular, faults that may be considered capable of displacing the ground surface, possibly affecting MX facilities. Potentially significant fault determinations were based on existing literature, photo-interpretation and field reconnaissance.

Faults shown on Drawing 2 include the northwesterly trending Sheep Mountain fault in the Gila Mountains, and an unnamed northwesterly trending fault along the westerly boundary of the Wellton Hills. An unnamed nearly east-west trending fault in the northeastern portion of the Wellton Hills is not shown due to scale of the map. The locations of these faults were determined from photolineaments on 1:24,000 scale color aerial photographs.

Photolineaments may be expressed by one or a combination of several features such as linearity of a mountain front or outcrops, alignment of offsets in stream channels, vegetation alignments, break in slope gradient, and alignment of depressions. These features may be surface expressions of faults, however, they may also represent such things as normal depositional contacts, differential erosion, foliation, jointing, and mineralogic changes.

Due to the limited scope of this investigation, determinations of the presence and, in particular, the capability of these

faults to displace surficial geologic units within the MX siting area were inconclusive. Detailed studies of such features should be performed during future validation and site-specific investigations.

Suspected faults interpreted from the geophysical investigation (Section 3.0) are not shown on Drawing 2 due to general lack of surface expression and probable absence of capability for displacing the ground surface within the MX siting area. The lack of such capability also precludes illustration of many other faults contained within the exposed rock units.

4.6.2 FAULTS

The Sheep Mountain fault, located in the northern Gila Mountains trends N65 to 70W with segments traceable over a length of five nm (17 km; Olmstead and others, 1973). Linearity of the surface trace of the Sheep Mountain fault on the aerial photographs indicates a vertical or steeply dipping fault plane although the angle of dip and amount of displacement are unknown. Trench LD-T-18 was excavated across the basinward projection (south-east) of the Sheep Mountain fault. No evidence of offset was found in Pleistocene-age materials exposed in the trench walls to a depth of 20 feet (6 m) below ground surface. An apparent subparallel branch of the Sheep Mountain fault (photolineament) may affect older and intermediate alluvial fan units (A50c and A5ic).

The linear western margin of the Wellton Hills forms a five nm (8 km) photolineament trending to the northwest. Trenches

LD-T-16, LD-T-17, LD-T-19, and LD-T-20 (Drawing B-1) were excavated in basin-fill deposits across the lineament trend, but no evidence of near-surface faulting was found in late Pleistocene to Holocene-age soils exposed in the trench walls. This lineament and its southerly branch may represent older (pre-Holocene) faulting which has affected materials below the depth of exploratory trenches, or it may represent an eroded fault scarp, whereas the fault may be concealed somewhat basinward of the mountain front.

An unnamed fault at least 800 feet (244 m) long strikes east-west in the extreme northern Wellton Hills juxtaposing sedimentary and metamorphic rock. A shallow excavation (LD-FS-137) 20 feet (6 m) long and two to three feet (60 to 90 cm) deep, perpendicular to the fault trace indicated granite-gneiss boulder conglomerate faulted against metamorphic rock. Rock units are separated by a highly weathered and altered clay-rich gouge zone more than 14 feet (4 m) wide. Slip planes and clay seams within this zone have strikes ranging from E-W to N15E with dips from 30N to vertical. The fault does not appear to extend into the adjacent basin fill.

Many small faults within rock were investigated in the Wellton Hills and Copper Mountains. These are generally traceable for less than 1000 feet (305 m) but are particularly evident due to alignments of mining operations and test pits along linear fault trends. Iron oxide, chrysocolla, and epidote fillings as well as fault gouge and slickensides occur along these

faults (Table 6). Fault orientations within exposed rock may be grouped into two general categories: 1) strike E-W, dip to the north (20° - 90°); 2) strike northwest (N25 - 60W), dip to the east (70° - 90°).

4.7 HYDROLOGY

4.7.1 SURFACE HYDROLOGY

Lechuguilla Desert lies entirely within the Gila Subregion of the lower Colorado Hydrologic Basin (Lower Colorado Region State-Federal Interagency, 1971). Unlike most of the Basin and Range Province where surface drainage is typically a closed-basin system (greater than 60 percent) draining into a playa, the surface drainage in Lechuguilla Desert is predominantly through-flowing via Coyote Wash to the Gila River (FN-TR-3, 1975c).

4.7.1.1 Perennial Systems

There are no perennial systems within the area of investigation in Lechuguilla Desert. Although, the Gila River, approximately four nm (6 km) north of the LBGR boundary (Figure 3), was historically a perennial stream, it is presently ephemeral due to damming for irrigation.

4.7.1.2 Ephemeral Systems

The ephemeral system in Lechuguilla Desert consists of numerous streams which flow during and immediately following short, intense thundershowers or long duration rainstorms. Thundershowers usually occur during the summer and fall, while most long duration rainstorms are more common during winter months (FN-TR-3, 1975c). The primary ephemeral stream channel in Lechuguilla Desert is Coyote Wash which drains north and northwest through the central Valley, diverging around and through the Wellton Hills towards the Gila River. Several other major drainages are located along the periphery of the Valley and

adjacent to the west side of the Wellton Hills (Drawing 2).

The Baker Tanks are a prominent hydrologic feature of Lechuguilla Desert. These natural rock tanks have been eroded into the arkosic sandstone immediately south of Baker Peaks and generally hold water most of the year. Numerous secondary ephemeral streams originate on the mountain flanks and in the Wellton Hills and are tributary or parallel to the primary drainages.

Depth of incision by ephemeral streams varies greatly. Both primary and secondary stream channels of the central Valley are characteristically shallow, ranging in depth from two to 36 inches (5 to 90 mm). Depth of incision increases upstream to ten to 20 feet (3 to 6 m) in the intermediate alluvial fan (A5i), and over 100 feet (30m) in the older (A5o) fan surfaces near mountain fronts (Section 4.3 and Table 5).

Widths of ephemeral drainages vary in the central Valley from well-defined individual channels of less than one foot (30 m), to Coyote Wash, which is a braided network of channels as much as 3000 feet (900 m) across. On the high fans along the Valley periphery, stream channels range in width from several feet (1 m) to over 200 feet (60 m).

Air photo analyses of stream densities generally within a mile (2 km) of the mountain fronts along the periphery of the Valley indicate a range from five to 25 per nautical mile (2 km). Average drainage densities generally increase with relative

alluvial fan unit age and are more deeply incised toward the mountain fronts.

Drainage densities range from 0 to 17 per nm (2 km) on younger alluvial fans (A5y); 9 to 25 on intermediate-younger fan units (A5iy); 9 to 20 on intermediate fan units (A5i); and 9 to 20 on older fan units (A5oc).

Central Valley stream channel gradients are nearly equal to the slope of the Valley floor, averaging just over one percent (Section 4.3). Stream gradients on the upper fans average approximately three percent (Section 4.3). Gradients on drainages originating in intrusive igneous rock are geneally lower due to the fine grained nature of deposits resulting from relatively rapid breakdown of these rocks.

Degree of cementation is an important factor affecting depth of incision. Ephemeral stream channels incised in the relatively well-cemented near-mountain intermediate alluvial fans channelize the runoff and intensify incision (Section 4.4.2). Uncemented deposits of the Central Valley have very little to no streambank stability. In these deposits ephemeral streams tend to form wide shallow channels that are somewhat transitory.

Many washes and stream channels throughout the Valley appear to have a temporary base level defined by the caliche horizon of the underlying intermediate alluvial fan. Drainages on the high level fans, because of their steeper gradient, have cut, or are cutting through the calichified horizon much more rapidly.

4.7.1.3 Surface Water Quality

A previous investigation (FN-TR-3, 1975c) indicated that in the ephemeral systems, water quality varies from fresh to moderately saline. Total dissolved solids (TDS) are generally much greater than 500 miligrams per liter (mg/1), with principal constituents being chlorides, sodium, and bicarbonate. No additional surface water quality data for Lechuguilla Desert were obtained during this field investigation.

4.7.1.4 Runoff Characteristics

Direct runoff is defined as water received at the surface in excess of the retention (amount of water necessary for soil saturation) loss rate (U.S. Bureau of Reclamation, 1973). Accurate calculations of the amount of direct runoff which can occur in Lechuguilla Desert are difficult because of the lack of accurate stream gauging data.

Some estimates of direct runoff for the area have been made in a previous report (FN-TR-3, 1975c). The estimates were 0.02 to over 0.5 inches (0.5 to 13 mm) of direct runoff per year in valley areas, increasing to over 2.5 inches (63.5 mm) over 30 percent of mean annual precipitation in mountain areas of greater than ten percent slope. In Lechuguilla Desert higher runoff values (0.5 inches, 13 mm) would apply to the pavemented fans (A5oc, A5iy), whereas the lower values (0.2 inches, 0.5 mm) would apply to unpavemented, uncemented basin-fill units (A5y, A3s, A3d, A1, A1/A5y).

4.7.1.5 Flooding Potential

Within Lechuguilla Desert, channel deposits are highly susceptible to flooding; younger alluvial fans and sheet sand deposits are relatively less susceptible, and older intermediate and intermediate-younger alluvial fans and sand dunes are least susceptible to flooding. No evidence was observed indicating the presence of recent debris flows during the field investigation.

Runoff is generally channelized quickly on alluvial fans where drainage is good. Areas where sheet flow occurs are restricted principally to higher fan surfaces which locally lack good drainage adjacent to the Gila and Copper Mountains. These topographically higher alluvial fan surfaces, their gradient and small catchment areas provide insufficient energy to move material larger than gravel-size. However, finer material (silt, sand, gravel) can be removed, resulting in the formation and subsequent headward erosion of channels draining the surface. Coarse particles greater than three inches (76 cm) are usually not moved in this manner, and debris flows carrying cobble to boulder-sized material would result only from high energy mountain runoff and most often be confined to incised stream channels. Scour and undercutting of banks occurs in these incised streams during high flow. Channel flow also predominates on younger fan surfaces. The complex drainage network of small braided channels in Lechuguilla Desert is capable of handling large volumes of water with little overbank flow.

A brief air and ground reconnaissance to assess flooding resulting

from Tropical Storm Doreen (15 to 16 August 1977) was made 17 and 18 August, 1977. Heaviest rainfall in the Yuma vicinity from this storm was 6.45 inches (164 mm) on 15 August, with a total of 7.01 inches (178 mm) over the two day period (Wayne McCarter, oral commun., 1977). Precipitation data from within the field area are lacking, but rainfall in Lechuguilla Desert was probably considerably less than at Yuma, Arizona. Measurements of depth of wetting indicate an increase on alluvial fans from five inches (125 mm) in the south to 12 inches (305 mm) in the north. Depth of wetting in stream channels was generally greater than 24 inches (600 mm).

Evidence for runoff from Tropical Storm Doreen was present in Lechuguilla Desert, particularly on the western side. Runoff was generally confined to existing channels on all alluvial fans. Flooding occurred only on younger alluvial fans where road berms, or other man made structures such as the canal berm interfered with natural drainage patterns and either ponded or diverted the flow.

4.7.2 GROUND-WATER HYDROLOGY

Ground water was not encountered within 125 feet (38 m) of the surface anywhere in Lechuguilla Desert. Borings deeper than 100 feet (30 m) were not prepared for a long duration ground water monitoring program; however, groundwater was recorded in four borings. Depth to ground water was substantiated during downhole geophysical logging of the borings by an abrupt scale shift.

Boring	Location	Surface Elevation	Depth to Groundwater	Groundwater Elevation
LD-B-1	East Central	870' (265 m)	125' (38 m)	745' (227 m)
LD-C-2	Northwest	490' (149 m)	153' (47 m)	337' (103 m)
LD-C-5	Southeast	870' (265 m)	248' (76 m)	622' (190 m)
LD-D-1	West Central	780' (238 m)	366' (112 m)	414' (126 m)

A previous report based on existing well data (FN-TR-3, Fugro National, Inc., 1975c) estimated depths to ground water greater than 100 feet (30 m) throughout the Valley, and greater than 400 feet (122 m) over 30 percent of the Valley.

5.0 SOILS ENGINEERING INVESTIGATION

5.1 OBJECTIVES

The primary objectives of the soils engineering investigation were to define the subsurface lithologic units and determine their general engineering properties. An evaluation of the relationships between source rock and grain sizes and also of the subsurface deposits with surficial geologic units was made in extrapolating limited data over a large area.

The engineering properties to be determined depend on the depth of the deposit. In the upper 20 to 30 feet (6 to 9 m), the important factors to be considered are excavatability and slope stability. The soil properties necessary in evaluating these factors are gradation, density, moisture content, degree of cementation, and shear strength. Some of the same properties are useful in evaluating the suitability of the excavated material for backfill and for determining the supporting capacity of recompacted materials for construction of roads. To evaluate the supporting capacity of the soils for foundations, the compressibility and shear strength of the soils within the zone subject to foundation stresses must be determined.

The soils engineering investigation also included a general evaluation of the deeper Valley sediments in order to provide some information for vulnerability and hardness consideration. General seismic velocity data for the basin-fill materials, the properties obtainable from velocity data, and the depth to rock (defined as V_p = 7000 fps; 2134 m/s) at the Valley perimeter have been presented in Section 3. To supplement these data,

basic soil properties from representative samples of the materials from the deeper borings have been determined and are presented in this section.

5.2 SCOPE

5.2.1 GENERAL

The objectives of the soils engineering investigation were accomplished with a program of drilling, trenching and testing of soil samples. The data obtained from these activities, in combination with the results of the geological and geophysical studies, were used to make a preliminary geotechnical evaluation of the site.

A Caterpiller 225 backhoe was used to excavate the trenches. Trench excavation provided first hand information on excavatability, slope stability and cementation. The open trench exposed the entire soil column to approximately 20 feet (6 m) for examination of soil layering and geologic structure.

The drilling program made use of hollow stem auger (CME-75), rotary air/wash (Failing 1500) and bucket auger (Watson 3000) drilling rigs. Most of the holes extending to a depth of 100 feet (30 m) or less were drilled with hollow-stem auger drilling equipment. In these holes, sampling was accomplished through the hollow augers with split spoon (Standard Penetration Test) and Fugro ring-lined drive samples. Bulk samples were also obtained from auger holes. Rotary drilling methods were used in the deeper holes and samples were taken with a Pitcher barrel sampler.

The testing program consisted basically of two parts: material identification tests and tests to determine engineering properties. Identification tests served to confirm or correct

visual field and laboratory classifications and included grain size analyses (sieve and hydrometer) and plasticity determination (liquid and plastic limits). Engineering parameters determined in the testing program include unit weight and moisture content, shear strength (direct shear, unconfined compression, static triaxial) and compressibility. Compaction tests were performed to determine backfill characteristics and California Bearing Ratio (CBR) tests were performed on remolded samples for road construction considerations. Limited chemical testing was also performed on samples from the upper 25 feet (8 m) to detect the presence of corrosive ions in the construction zone. Procedures used for the trenching, drilling, and soils testing activities are summarized in Appendix F of FN-TR-18.

5.2.2 FIELD INVESTIGATION

5.2.2.1 Trenching

A total of 23 trenches were excavated in the alluvial fan deposits adjacent to the mountain fronts and central portions of the Valley. Three of the trenches were near the sedimentary rocks of the Copper Mountains, three near the igneous rocks of the Copper Mountains, four near the igneous rocks of the Gila Mountains, two near the metamorphic rocks of the Gila Mountains, five near the metamorphic rocks of the isolated rock outcrops in the north-central Valley, and the remaining six in the younger alluvial fans (A5yf) in the central portion of the Valley. Their locations are shown on the Activities Location Map (Drawing 1).

Unless caving occurred during excavation, trench widths were three feet (0.9 m). The depth of excavation was generally

20 feet (6.1 m) except in LD-T-5, LD-T-6, LD-T-17, LD-T-19, LD-T-21, and LD-T-22, where difficult digging was encountered at shallower depths.

The trenches were logged and bulk samples of 30 to 50 pounds (13 to 23 kg) were obtained in each lithologic unit. Hydraulic shoring was installed prior to entering the trenches. The trench logs and photographs illustrating trench conditions and shoring are included in Appendix C (Figures C-41 through C-68).

5.2.2.2 Drilling

The 39 borings drilled in Lechuguilla Desert were relatively evenly distributed throughout the study area as shown on the Activities Location Map (Drawing 1). Boring spacing was typically two to three nautical miles (4 to 6 km). Total footage of the engineering borings in the Valley was 6328 feet (1929 m).

The borings were assigned letter designations in accordance with nominal depths drilled as explained below:

Designation	Nominal Depth of Boring	Number of Borings
A	50 feet (15 m)	17
B	100 feet (30 m)	15
C	300 feet (92 m)	6
D	1000 feet (305 m)	3

Nearly all of the A and B borings were drilled with hollow stem auger drill rigs while rotary air/wash rigs were used for the C and D borings. A bucket auger was also used in two of the B borings. The final logs of all engineering borings are presented in Appendix C.

Borings LD-B-7, LD-B-8, LD-B-9, and LD-B-18 were drilled at the same location to compare the effect of weight of hammer and sampling techniques on blowcount and sample recovery. Borings LD-A-10 and LD-C-3 were also drilled at the same location to compare the effect of Fugro drive and Pitcher tube sampling techniques on moisture content and in situ density of the samples obtained. Another comparison study was made at borings LD-B-14 and LD-B-15, where hollow stem auger and bucket auger techniques were used.

5.2.2.3 Sampling

Relatively undisturbed samples were obtained in all engineering borings at intervals varying from five feet to 100 feet (1.5 to 30 m), depending on the depth below ground surface. Sample intervals were modified as drilling progressed, depending on the variation and types of soils encountered. In the A borings, samples were generally obtained at five-foot (1.5 m) intervals to a depth of 40 feet (12.2 m) and one sample was obtained at 50 feet (15.2 m). The normal sampling interval in the B, C, and D borings is shown in the following table.

Sampling Interval		Depth Range	
Feet	Meters	Feet	Meters
5	1.5	0-20	0-6
10	3.0	20-100	6-30
25	8	100-300	30-91
50	15	300-500	91-152
100	30	500-1000	152-305

When drilled to nominal depth, the usual number of samples per boring is nine for A, 12 for B, 20 for C, and 29 for D borings. Soil samples in the auger holes were taken with Fugro drive and split spoon samplers while those in rotary holes were taken with Pitcher samplers. A split spoon sampler was used when no recovery could be obtained with the Fugro drive sampler. A total of 201 Pitcher, 303 drive (ring-lined and split spoon), and 87 bulk samples were obtained.

Coring techniques were used in borings LD-B-1, LD-B-17, LD-C-5, LD-D-2, and LD-D-3, where partially indurated deposits were encountered and sampling with a Pitcher barrel sampler was not possible. A total of 59 feet (18 m) of NC core (2.74 inches; 70 mm) was recovered, 42 feet (13 m) of which was obtained from basement rock.

5.2.3 LABORATORY INVESTIGATION

A field laboratory was established in Tacna, Arizona to perform classification tests on samples as they were received from the field. The tests included gradation, density, moisture content and Atterberg limits. The classification tests were then conveyed to the personnel performing visual borehole logging at the drilling rigs, thereby minimizing the inconsistency between the lab test results and field visual classifications. Field laboratory tests were also used to determine the suitability of the samples for further testing.

The suitable samples were then shipped to Fugro National's Long Beach laboratory for further testing. The following tests were performed on selected samples in the Long Beach laboratory to

further define the engineering characteristics of the subsurface soils:

- Direct Shear
- Unconfined Compression
- Static Triaxial Shear
- Consolidation
- Compaction
- California Bearing Ratio (CBR)
- Specific Gravity
- Chemical Tests

All tests were performed in general accordance with ASTM procedures. Details of the laboratory test procedures are presented in Appendix F of FN-TR-18 and results are included in Appendix C of this report.

5.3 SUBSURFACE SOIL PROPERTIES

5.3.1 GENERAL

The discussion of subsurface soil properties has been divided into two sections; Section 5.3.2 discusses the properties of the deposits in the upper 50 feet (15.2 m) which is defined as the construction zone. Section 5.3.3 discusses the properties of the deposits encountered at depths greater than 50 feet (15.2 m) below existing ground surface. The data obtained in the deeper zone are important in the evaluation of vulnerability and hardness.

In presenting data, ranges in values and average values are presented for various soil parameters. It must be recognized that the amount of data decreases with depth and that in Section 5.3.3, much of the data are based on samples obtained between a depth of 50 and 100 feet (15 and 30 m). Thus, the average values may not be representative of the entire depth range between 50 feet (15 m) and 1000 feet (305 m). All of the test results are presented in Appendix C (Tables C-1 through C-7 and Figures C-2 to C-258) so that specific test results can be used if more appropriate than the average values presented in the following sections.

5.3.2 GROUND SURFACE TO 50 FEET (15 METERS)

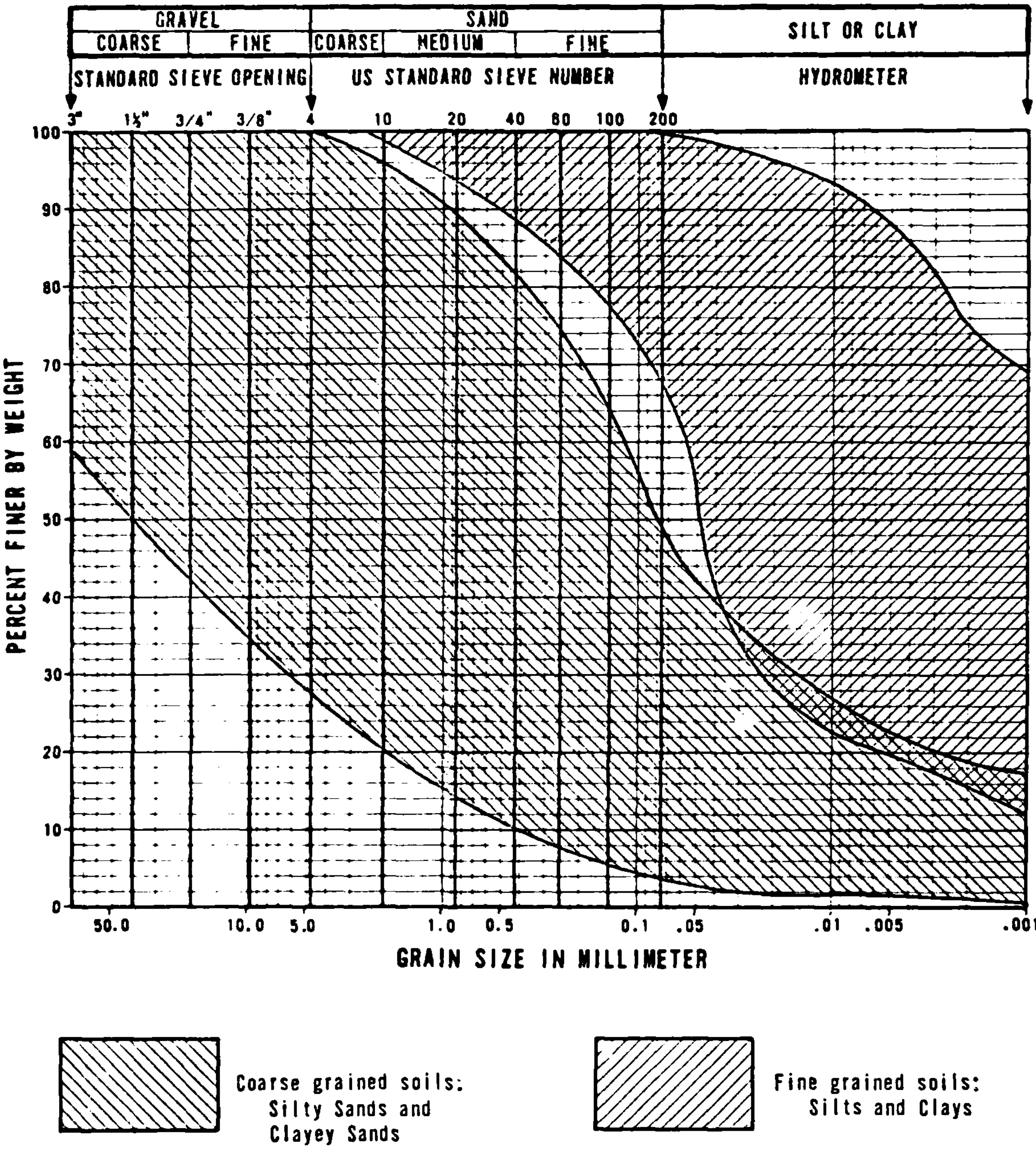
5.3.2.1 Grain Size Distribution

The shallow deposits of Lechuguilla Desert are predominantly silty and clayey sands. The fines content in silty and clayey sands throughout the Valley generally varies from 12 to 40 percent. Quantities of fines less than 12 percent are rare and are usually

encountered near the mountain fronts and northern portions of the Valley. Deposits underlying the younger alluvial fans (A5y and A5yf) generally contain 25 to 40 percent fines. The thickness of the younger fan unit is generally less than five feet and its areal extent is illustrated on the Geologic Map (Drawing 2). The gradation ranges of the Valley deposits in the upper 50 feet (15 m) are presented in Figure 21.

The size and amount of gravel, cobbles and boulders increases towards the mountain fronts and isolated rock outcrops. This trend is particularly prominent within one-half mile (1 km) of the mountain fronts, generally within the extent of the surface exposures of intermediate alluvial fan units (A5i and A5iy) and older alluvial fans (A5oc). In the central portion of the Valley, underlying the younger alluvial fan deposits (A5yf), the percentage of gravel, cobbles and boulders is consistently lower than ten percent and the maximum particle size observed is eight inches (20 cm).

In the northeast corner of the Valley, along the face of Copper Mountains, where the source rock is sedimentary, soils comprise ten to 30 percent gravel, decreasing to less than ten percent at distances greater than two miles (3 km) from the mountain front. The largest particle size encountered in this near-mountain region is about 12 inches (30 cm). However, in the southeast corner of the Valley, where the source rock is igneous, the percentage of gravel is consistently lower than 15 percent within one-half mile (1 km) of the mountain fronts (underlying the finer grained intermediate and intermediate-younger alluvial fan units (A5iyf)) and the largest particle size encountered is six inches (15 cm).



GRADATION RANGE UPPER 50 FEET (15 m) LECHUGUILLA DESERT, ARIZONA	
MX SITING INVESTIGATION DEPARTMENT OF THE AIR FORCE - SAMSO	FIGURE 21

FUGRO NATIONAL, INC.

In the western part of the Valley, along the middle and south portions of Gila Mountains, where the source rock is igneous, the percentage of gravel is generally less than 15 percent within one-half mile (0.8 km) of the mountain fronts (intermediate younger alluvial fan units) and the maximum particle size encountered is 14 inches (36 cm). Further north along the face of the Gila Mountains, where the source rock is metamorphic, the gravel content often exceeds 50 percent within three miles (5 km) of the mountain front and the maximum particle size encountered in the trenches is about 24 inches (60 cm).

Fine grained units of predominantly clay deposits in the shallow subsurface wer primarily encountered at the northern and eastern portions of the Valley. The thickness of these deposits in the upper 50 feet (15 m) is generally less than 20 feet (6 m) and they were encountered as shallow as three feet (1 m) below the ground surface at trench LD-T-4 in the northern end of the Valley. LD-B-16 is the only boring at which the thickness of the clay layer exceeds 20 feet (6 m). It was first encountered at a depth of eight feet (2m) and extends deeper than 50 feet (15 m) below the ground surface where it is underlain by silty sand at approximately 95 feet (29 m). This deposit is discussed in further detail in Section 5.3.3.1. since a portion of this, and all other fine grained units are encountered below 50 feet (15 m).

5.3.2.2 Unit Weight

The unit weight of each suitable Fugro drive and Pitcher tube sample was determined and results are presented on the boring logs

(Appendix C). Average dry unit weights show some variation among different soil types. In the coarse grained soils, the average dry unit weight is approximately 115 pcf (1842 kg/m^3), while in fine grained soils it is 106 pcf (1698 kg/m^3). The effect of disturbance due to hard driving conditions is not significant. In silty sands the average dry unit weight of Fugro drive samples and Pitcher tube samples are the same, 115 pcf (1842 kg/m^3). However, in clayey sand samples, the average dry unit weight of Fugro drive samples is 114 pcf (1826 kg/m^3), while for Pitcher tube samples it is 117 pcf (1874 kg/m^3). The difference is somewhat less pronounced in clays, with an average of 105 pcf (1682 kg/m^3) for drive samples and 106 pcf (1698 kg/m^3) for Pitcher samples. The dry unit weight range and averages of all soil types are presented below:

Dry Unit Weights, Fugro Drive Samples

Soil Type	Range in Dry Unit Weights pcf	Range in Dry Unit Weights kg/m3	Average Dry Unit Weight pcf	Average Dry Unit Weight kg/m3	Number of Samples Tested
Silty Sands	91-135	1458-2162	115	1842	44
Clayey Sands	92-124	1474-1986	114	1826	40
Silts	-	-	-	-	-
Clays	90-129	1442-2066	105	1682	6

Dry Unit Weights, Thin-Walled Pitcher Tube Samples

Soil Type	Range in Dry Unit Weights pcf	Range in Dry Unit Weights kg/m3	Average Dry Unit Weight pcf	Average Dry Unit Weight kg/m3	Number of Samples Tested
Silty Sands	102-127	1634-2034	115	1842	55
Clayey Sands	105-129	1682-2066	117	1874	50
Silts	-	-	-	-	-
Clays	97-114	1554-1826	106	1698	6

Since a lesser amount of sample disturbance is caused by thin--walled Pitcher tube samplers, the values obtained by this method are more representative of the in situ dry unit weights and should be used in all unit weight calculations.

5.3.2.3 Moisture Content

The moisture content of each boring sample was determined and results are presented on the boring logs (Appendix C). Considerable variation in results was observed with different drilling methods and soil types. The moisture content variation with depth for dry and rotary-wash holes is illustrated on Figures C-69 and C-70 (Appendix C).

Borings LD-A-10 and LD-C-3 were drilled approximately 25 feet (8 m) apart to compare the effect of drilling and sampling methods. LD-A-10 was drilled with a hollow-stem auger (dry) and samples were taken with a Fugro drive sampler, while LD-C-3, a mud filled rotary-wash hole was sampled with a Pitcher tube sampler. The moisture content results illustrate the tendency of drilling mud used in rotary wash holes to increase the moisture content of samples in relatively dry soils (Figure C-71; Appendix C).

Average moisture contents and ranges for different soil types are presented below:

Average Moisture Content (%)

Soil Type	Hollow Stem Auger (Dry) Holes	Number of Samples Tested	Rotary Wash Holes	Number of Samples Tested
Silty Sand	1.9	139	11.5	48
Clayey Sand	3.5	77	10.1	45
Silt	5.6	3	-	-
Clay	9.8	15	18.1	6

Range in Moisture Content (%)

Soil Type	Dry Holes	Rotary-Wash Holes
Silty Sand and Clayey Sand	0.2-12.1	4.7-19.8
Silt and Clay	1.8-26.6	10.1-24.7

Moisture content results obtained in dry holes should be used in moisture calculations since Pitcher tube results do not as accurately represent the in situ moisture conditions due to the drilling fluid infiltration.

5.3.2.4 Cementation

Subsurface investigation throughout the Valley reveals that various degrees of cementation are present in most lithologic units in the upper 50 feet (15 m). Various degrees of cementation were observed in all 23 trenches excavated throughout the Valley and in some geologic test pits throughout the Valley basin. The samples obtained from almost all borings also indicate the presence of cementation to various degrees. Type of cementation in the Valley is principally calcium carbonate, although silica type cementing was occasionally

observed in the older buried alluvial fan deposits in the northwestern portion of the Valley.

Younger alluvial fans, the most areally exposed units, predominantly exist in the central basin and cover approximately 51 percent of the Valley. These units are generally less than five feet (1.5 m) thick and exhibit little or no cementation.

Intermediate-younger fans cover about nine percent of the Valley, principally near the mountain fronts. The thickness of this unit is usually less than ten feet (3 m) and the degree of cementation is generally weak.

The intermediate alluvial fan unit covers about nine percent of the Valley, generally occurring adjacent to the mountain fronts and as isolated remnants in the Central Basin. Cementation in this unit ranges from weak to strong, but is generally moderate. This unit occurs uniformly in the shallow subsurface underlying the younger and intermediate-younger alluvial fan units.

During trenching operations some very strongly cemented layers were encountered at depths as shallow as 12 feet (4 m) in areas near isolated rock outcrops in the north-central Valley and in the intermediate and older alluvial fan units (A5ic and A5oc) in the northwestern portion of the Valley. The extent of such materials is not known, although, based on compressional wave velocity and other subsurface data, it appears that highly cemented layers are locally encountered adjacent to mountain fronts or isolated rock outcrops.

5.3.2.5 Shear Strength

A testing program consisting of static triaxial shear tests, unconfined compression and direct shear tests was performed on selected soil samples to obtain general shear strength parameters of the site soils. The results are presented on Tables C-3, C-4, and C-5 and Figures C-72 through C-103 in Appendix C.

The predominant soil type in the upper 50 feet (15 m) is silty to clayey sand. Consolidated-drained triaxial tests were performed on 28 samples of this type of soil at confining pressures generally approximating the overburden pressures. The samples were sorted into nine groups, each having similar gradations. In most groups, one or two samples were from depths less than 50 feet (15 m), while the remaining sample(s) were from depths greater than 50 feet (15 m). Thus, the shear parameters obtained represent the general strength characteristics of silty and clayey sands of the entire depth. A failure envelope was plotted for each group of samples to determine the angle of friction and the cohesion. The friction angles (ϕ), range from 31 to 39 degrees (31° to 39°) and the range of the cohesion intercept (c) is approximately 0 to 3 kips per square foot (ksf) (0 to 144 kilonewtons per square meter [kN/m^2]).

Unconfined compression tests were performed on 28 samples of silty and clayey sands in the upper 50 feet (15 m). The range of unconfined compressive strengths for these samples varied from 0.4 to 9.5 ksf (19 to 455 kN/m^2) with an average of 2.8 ksf (134 kN/m^2).

A total of 44 direct shear tests were performed on silty and clayey sands in the upper 25 feet (7.6 m). Most samples were tested at various normal stresses to obtain the failure envelope. The total shear strengths under the normal stress approximating the in situ overburden pressure ranged from 0.8 to 4.4 ksf (38 to 211 kN/m^2), with an average of 1.8 ksf (86 kN/m^2). Some results may have been affected by sample disturbance mainly during the sampling process and the extrusion of the sample into the direct shear testing apparatus.

A p - q diagram was plotted to graphically summarize all triaxial tests performed and to determine the general strength characteristics of the site soils (Appendix C Figure C-72). A p - q diagram is defined as $\frac{\sigma_1 + \sigma_3}{2}$ versus $\frac{\sigma_1 - \sigma_3}{2}$, where σ_1 is the maximum stress, and σ_3 is the confining pressure for the triaxial test. Based on a straight-line fit of results in the p-q diagram and other tests, the "typical" angle of internal friction and the "typical" cohesion value for silty and clayey sands are 34° and 1.2 ksf (57 kN/m^2), respectively.

Localized areas of fine grained deposits (clays and sandy silts) were encountered in the upper 50 feet (15 m) within certain portions of the site (Section 5.3.2.1). Three unconfined compression tests were performed on these samples and unconfined compressive strengths ranged from 1.6 to 14.1 ksf (77 to 675 kN/m^2) with an average of 6.4 ksf (306 kN/m^2). Strength characteristics of fine grained materials are discussed in further detail in

Section 5.3.3.5, since these soils are encountered more extensively below 50 feet (15 m).

5.3.2.6 Compressibility

Consolidation tests were performed on 13 representative samples to provide an indication of the compressibility of the soils in the upper 50 feet (15 m). All samples showed very little compression on the reload curve and they can be classified as only slightly compressible. The percentage of consolidation at 14 ksf (766 kN/m^2) did not exceed three percent in any of the samples and generally was less than 2.5 percent. The moderate to high percentage of consolidation of some samples during the first cycle of loading suggests sample disturbance probably during the sampling process. The results are presented in Figures C-104 through C-113, Appendix C.

After the second cycle of loading, all samples were saturated at a load of 2 ksf (96 kN/m^2) to determine the potential for volume change when the samples were subjected to increased moisture conditions. The volume change noted due to submerging the samples ranged from approximately six percent expansion (swell) for a highly plastic clay to approximately 2.5 percent compression for a clayey sand. The highest percentage of compression due to saturation was observed in a clayey sand sample obtained from boring LD-A-4 (Figure C-109). This sample had a relatively low dry unit weight of about 95.2 pcf (1525 kN/m^3) which is indicative of sample disturbance.

5.3.2.7 California Bearing Ratio (CBR)

CBR tests were performed on four samples designated A, B, C, and D and representing the range of predominant soil types and gradations encountered in the upper 20 feet (6 m). Each of the four samples tested was a composite of three bulk samples of similar gradation obtained from exploratory trenches and/or borings. Test results and related gradations are presented on Table C-6 and Figures C-114 and C-115; Appendix C.

Samples C and D were clayey sands with fines contents of 14 and 28 percent, respectively and had lower CBR values than samples A and B at corresponding compaction efforts. At 90 percent relative compaction, the C and D CBR value was approximately nine, while at 95 percent it was about 18. The other two composite samples (A and B) were predominantly silty sanas with fines contents ranging from 24 to 34 percent. CBR tests performed on these samples indicated results of approximately 18 and 50 at relative compactions of 90 and 95 percent, respectively.

CBR values of 10 to 14 generally indicate "good", and values greater than 14 indicate "excellent" subgrade soil quality. Based on these data, over 80 percent of the site soils in the construction zone should have "good" or "excellent" subgrade soil quality when compacted to at least 90 percent of maximum dry density.

5.3.2.8 Compaction

A total of 13 compaction tests were performed on bulk samples obtained from the upper 20 feet (6 m) and the results are

included in Figures C-116 through C-121, Appendix C. Nine of those samples were individual bulk samples from exploratory borings and trenches. The remaining four were composite samples, prepared by combining similarly graded samples, which were used in the CBR testing program.

Maximum dry densities for silty sands and clayey sands ranged from 128.8 pcf (2063 kg/m^3) to 134.8 pcf (2159 kg/m^3), and the range of optimum moisture content was 7.0 percent to 9.6 percent. Maximum dry densities and optimum moisture contents for the other soil types are listed below:

Soil Type	Maximum Dry Density		Optimum Moisture
	pcf	kg/m^3	content (%)
Sandy Gravel (GP/GM)	134.0	2146	8.1
Silt (MH)	104.0	1666	21.0
Clay (CL)	128.9	2065	8.6

Based on these data, some shrinkage is expected to occur if the natural soils are compacted as backfill. Assuming that the backfill is compacted to an average of 92 percent of maximum dry density, the average percent shrinkage, with respect to the volume of natural soils excavated as compared to the resulting volume of compacted fill, is estimated to be about five percent. This average is based on a maximum dry density of 133 pcf (2131 kg/m^3) and an average in situ dry density of 116 pcf (1858 kg/m^3).

5.3.2.9 Chemical Tests

Limited chemical testing was performed on 18 samples from 13 of the borings and five of the trenches. Tests for water

soluble sulfate, water soluble chloride, water soluble sodium, and soil pH were performed and the results are presented on Table C-7, Appendix C. The range in water soluble sulfate was from three to 9,490 mg/kg based on dry weight of the soil sample. Water soluble sodium ranged from 69 to 3,375 mg/kg; water soluble chloride ranged from 46 to 4,570 mg/kg. The range of soil pH for the samples tested was from 7.5 to 8.1.

Based on the "Design and Control of Concrete Mixtures" prepared by the Portland Cement Association, the soluble sulfate content of 15 of the 18 samples tested should result in negligible to mild sulfate attack on concrete. However, the remaining three samples contained sulfate contents which could result in severe sulfate attack. Although no general statements can be made from these limited data, the use of high sulfateresistant cement (Type V) would be necessary in some areas for structural concrete elements in contact with the soil.

5.3.3 DEEPER THAN 50 FEET (15 METERS)

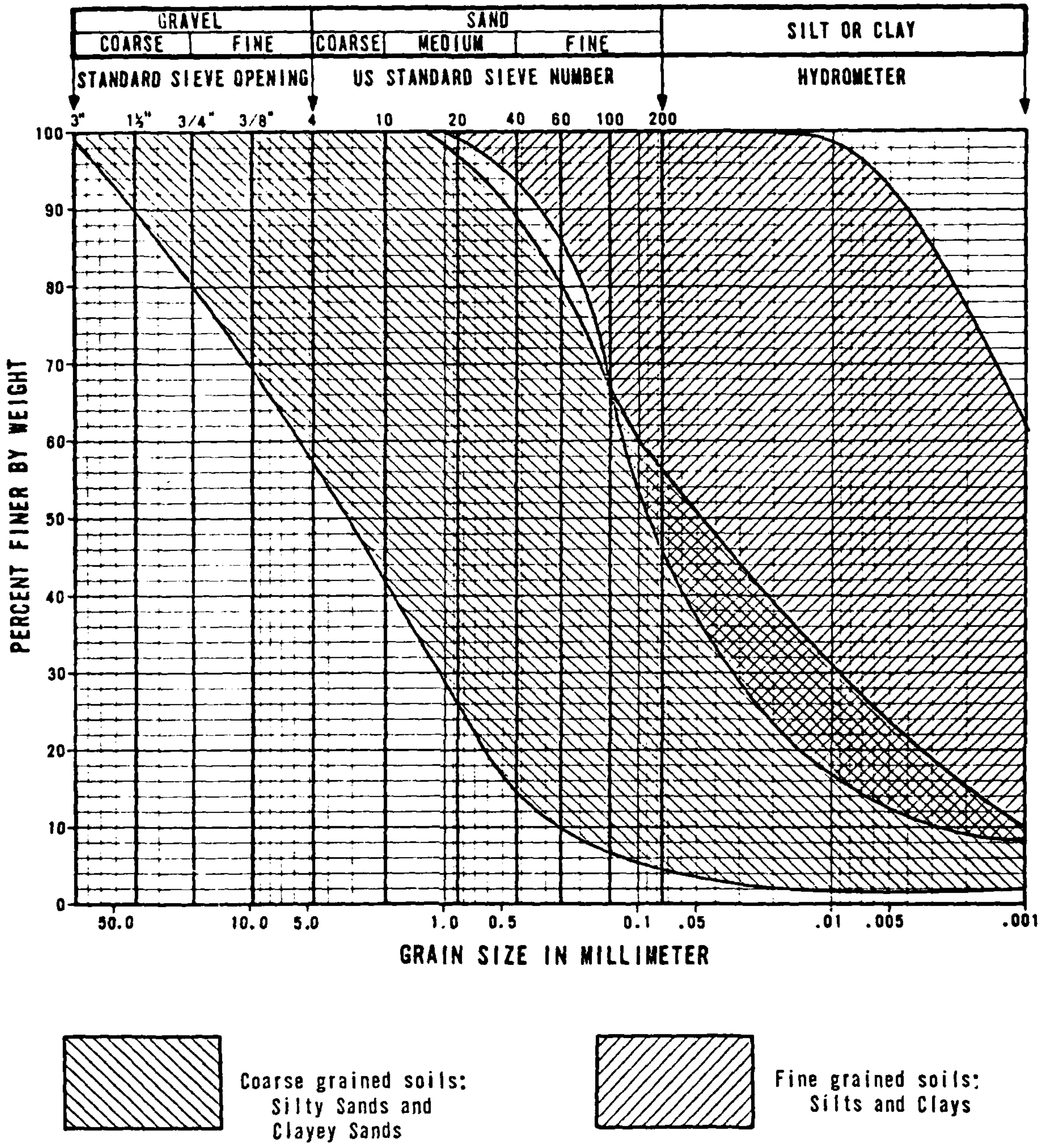
5.3.3.1 Grain Size Distribution

The pattern of grain size distribution in the deep deposits is similar to that in the upper 50 feet (15 m). Again, silty and clayey sands were predominantly encountered and the gravel content decreases away from the mountain fronts. The percentage of fines in silty and clayey sands is generally slightly higher than those in the shallow deposits. The range of fines within two statute miles (3 km) of the mountain fronts is generally 15 to 30 percent, and increases to 15 to 45 percent in the Central Valley.

The gradation ranges of deposits below 50 feet (15 m) are presented in Figure 22.

The exact size and amount of gravel, cobbles and boulders below 50 feet (15 m) is not known due to the limited number and size of samples obtained. However, based on field observations, the percentage of gravel, cobbles and boulders is generally less than 30 percent near the mountain fronts and isolated rock outcrops decreasing to less than ten percent in the central portions of the Valley in the deposits underlying the younger alluvial fans (15yf).

Fine grained units of predominantly clay deposits comprise a larger portion of the materials below 50 feet (15 m) than those above 50 feet (15 m) and were encountered at various isolated areas throughout the Valley. The deepest fine grained deposit was encountered in the southern half of the Valley at boring LD-D-1 at 86 feet (26 m) below ground surface (elevation 689 feet; 210 m) and continues to the full depth of the boring at 800 feet (243 m), interrupted three times by silty sand deposits at various depths. LD-C-4 is another boring in the southern half of the Valley at which a clay deposit was encountered. The thickness of this deposit is approximately nine feet (3 m) and begins at 56 feet (17 m) below the ground surface at elevation 844 feet (257 m).



GRADATION RANGE
50 TO 300 FEET (15 TO 91 m)
LECHUGUILLA DESERT, ARIZONA

MX SITING INVESTIGATION
DEPARTMENT OF THE AIR FORCE - SAMSO

FIGURE 22

FUGRO NATIONAL, INC.

Fine grained deposits are more areally scattered in the northern half of the Valley. At borings LD-C-2 and LD-C-3, located in the northwestern portion of the Valley, fine grained deposits continue to the full depth of the borings. At LD-C-2, the fine grained deposit begins at 41 feet (13 m) below ground surface (elevation 449 feet; 137 m) interrupted twice by silty sand deposits. The thickness of this deposit is not known, as it continues to the full depth of the boring at 301 feet (92 m). At LD-C-3 fine grained deposits are encountered in relatively thin layers at 147 feet (45 m), and 248 feet (76 m) below ground surface. At 295 feet (90 m) a fine grained layer is encountered which continues to the full depth of the boring at approximately 302 feet (92 m).

In the north-central portions of the Valley a relatively extensive fine grained deposit is encountered at borings LD-B-16 and LD-C-6 near elevation 485 feet (148 m). At LD-B-16 the fine grained deposit begins at eight feet (2 m) below ground surface and continues practically uninterrupted to a depth of about 94 feet (29 m), where it is underlain by silty sand and sandy silt. However, at LD-C-6, the clay deposit is only about 15 feet (5 m) thick, beginning at a depth of about 73 feet (22 m). Further south, at LD-D-2, a 14 foot (4 m) thick fine grained deposit is encountered at 172 feet (52 m) below ground surface, near elevation 498 feet (152 m).

At the north-central boundary of the Valley, at borings LD-B-2 and LD-B-17, a fine grained deposit was also encountered at

elevations 310 feet (94 m) and 366 feet (112 m), respectively. At LD-B-2 the fine grained deposit begins at 90 feet (27 m) and has a thickness of 11 feet (3 m), and at LD-B-17 it begins at a depth of 24 feet (7 m) and has a thickness of 36 feet (11 m).

5.3.3.2 Unit Weight

The variation of dry unit weights below 50 feet (15 m) is similar to that in the shallower deposits. In the coarse grained soils, the average dry unit weight is approximately 116 pcf (1858 kg/m^3), while in fine grained soils it is about 107 pcf (1714 kg/m^3). The dry unit weight results obtained by Fugro drive and Pitcher tube samplers do not indicate any significant variation except in silty sands where the average obtained by Fugro drive samplers and Pitcher tubes are 110 pcf (1762 kg/m^3) and 117 pcf (1874 kg/m^3), respectively. The dry unit weight range and averages of all soil types are presented below:

Dry Unit Weights, Fugro Drive Samples

Soil Type	Range in Dry Unit Weights pcf	Range in Dry Unit Weights kg/m^3	Average Dry Unit Weight pcf	Average Dry Unit Weight kg/m^3	Number of Samples Tested
Silty Sands	97-123	1554-1970	110	1762	13
Clayey Sands	105-126	1682-2018	117	1874	8
Silts	-	-	-	-	-
Clays	105-111	1682-1778	108	1730	3

Dry Unit Weights, Pitcher Tube Samplers

Soil Type	Range in Dry Unit Weights pcf	kg/m3	Average Dry Unit Weight pcf	kg/m3	Number of Samples Tested
Silty Sands	97-139	1554-2227	117	1874	76
Clayey Sands	100-128	1602-2178	116	1858	21
Silts	95-119	1522-1906	106	1698	14
Clays	91-122	1458-1954	106	1698	31

Dry unit weights from thin-walled Pitcher tube samples are more representative of the in situ conditions and should be used in all unit weight calculations.

5.3.3.3 Moisture Content

The moisture content of each boreing sample was determined and results are presented on the boring logs. The data indicate that there is considerable variation in moisture contents due to different drilling methods as previously discussed in Section 5.3.2.3. Average moisture contents and ranges for different soil types are presented below:

Average Moisture Content (%)

Soil Type	Hollow-Stem Auger (Dry) Holes	Number of Samples Tested	Rotary Wash Holes	Number of Samples Tested
Silty Sand	2.2	68	11.3	81
Clayey Sand	3.6	12	10.8	21
Silt	-	-	16.2	15
Clay	15.3	10	18.3	31

Range in Moisture Content (%)

Soil Type	Dry Holes	Rotary-Wash Holes
Silty Sand and Clayey Sand	0.3-17.2	3.7-22.0
Silt and Clay	3.8-25.7	7.7-33.8

Moisture content results obtained in dry holes should be used in all moisture calculations. Pitcher tube results do not represent the in situ moisture conditions due to the drilling fluid infiltration.

5.3.3.4 Cementation

Due to the limited number of borings, the degree of cementation below 50 feet (15 m) cannot be accurately defined. However, high blowcounts encountered throughout the depths of all borings with drive sampling and the reaction of most samples to dilute hydrochloric acid (HCl) indicates that cementation to some degree exists in most lithologic units. Reaction to HCl further indicates that the principal cementing agent in most deposits is calcium carbonate.

5.3.3.5 Shear Strength

The predominant soil types below 50 feet (15 m) are silty and clayey sands. The triaxial testing program performed on these soils and the results have been discussed in detail in Section 5.3.2.5. Unconfined compression tests were performed on eight silty and clayey sand samples below 50 feet (15 m). The unconfined compressive strengths for these samples ranged from 0.7 to 5.0 ksf (34 to 239 kN/m^2), with an average of 1.8 ksf (86 $kN/m2$).

Extensive deposits of fine grained soils were encountered in portions of the Valley, below 50 feet (15 m). Consolidated drained triaxial tests were performed on eight samples of these deposits, with all samples tested at confining pressures approximately equal to the overburden pressures. The samples were sorted into four groups with each sample in a group having similar gradations. The measured friction angles (ϕ) range from 0° in clays with high plasticity to 33° in sandy silts, and the range of the cohesion intercept (c) is approximately one to 21 ksf (48 to 1005 kN/m^2). The large range of and c is probably due partly to the fact that there is a wide variation among samples in the degree of saturation, which has a significant effect on the shear strength of fine grained soils. The degree of cementation also has a substantial effect on the apparent strength of the sample.

Unconfined compression tests were performed on ten samples of the fine grained soils obtained from deeper than 50 feet (15 m). The range in unconfined compressive strength for these samples is 3.1 to 17.4 ksf (148 to 833 kN/m^2) with an average of 11.9 ksf (570 kN/m^2). These values are considerably higher than the ones obtained in the upper 50 feet (15 m).

The results of all triaxial shear tests performed on fine grained soils are also plotted on the same p-q diagram with silty and clayey sand results (Appendix C, Figure C-72). A p-q diagram is defined in Section 5.3.2.5. Based on a straight line fit of the p-q plots and other tests performed on fine grained

soils below 50 feet (15 m), the "typical" angle of internal friction and the "typical" cohesion values for fine grained soils are 24° and 5 ksf (240 kN/m^2), respectively.

GLOSSARY OF TERMS

GLOSSARY OF TERMS

ACTIVITY NUMBER - A designation composed of the valley abbreviation followed by the activity type and a unique number; may also be used to designate a particular location in a valley.

AEROMAGNETIC DATA - Magnetometer observations made from a moving airplane.

ALLUVIAL BASIN - A lowland area, generally between uplifted mountain blocks, that is filled with alluvial deposits.

ALLUVIAL FAN - A low, outspread, relatively flat to gently sloping mass of alluvium, shaped like an open fan or a segment of a cone, deposited by a stream (especially in a semiarid region) at the place where it issues from a narrow mountain valley upon a plain or broad valley. It is steepest near the mouth of the valley where its apex points upstream, and it slopes gently and convexly outward with gradually decreasing gradient.

ALLUVIAL FAN DEPOSITS - Alluvium deposited by a stream or other body of running water as a sorted or semi-sorted sediment in the form of a cone or fan at the base of a mountain slope.

ALLUVIAL PLAIN - A level or gently sloping tract or a slightly undulating land surface produced by extensive deposition of alluvium, usually adjacent to a river that periodically overflows its banks; it may be situated on a flood plain, a delta, or an alluvial fan.

ALLUVIUM - A general term for unconsolidated clay, silt, sand, gravel, and boulders deposited during relatively recent geologic time by a stream or other body of running water as a sorted or semisorted sediment in the bed of the stream or on its flood plain or delta, or as a cone or fan at the base of a mountain slope.

ANOMALY - 1) A deviation from uniformity in physical properties; especially a deviation from uniformity in physical properties of exploration interest. 2) A portion of a geophysical survey which is different in appearance from the survey in general.

ARKOSIC SANDSTONE - A sandstone with considerable feldspar, such as one containing minerals from coarse-grained quartzofeldspathic rocks (granites, granodiorites, medium or high-grade schists) or from older, highly feldspathic sedimentary rocks; specifically a sandstone containing more than 25% feldspar and less than 20% matrix material of clay, sericite, and chlorite.

GLOSSARY OF TERMS

ARRIVAL - An event; the appearance of seismic energy on a seismic record; a line-up of coherent energy signifying the arrival of a new wave train.

ATTERBURG LIMITS - A general term applied to the various tests used to determine the various states of consistency of fine grained soils. The four states of consistency are solid, semisolid, plastic, and liquid.

Liquid limit (LL) - The water content corresponding to the arbitrary limit between the liquid and plastic states of consistency of a soil (ASTM D423-66).

Plastic limit (PL) - The water content corresponding to an arbitrary limit between the plastic and the semisolid states of consistency of a soil (ASTM D424-59).

Plasticity index (PI) - Numerical difference between the liquid limit and the plastic limit.

BASIN-FILL MATERIAL/BASIN-FILL DEPOSITS - Heterogenous detrital material deposited in a sedimentary basin.

BOUGUER ANOMALY - The residual value obtained after latitude, elevation and terrain corrections have been applied to gravity data.

BULK SAMPLE - A disturbed soil sample (bag sample) obtained from cuttings brought to the ground surface by a drill rig auger or obtained from the walls of a trench excavation.

CALIFORNIA BEARING RATIO (CBR) - A test performed on a specifically prepared soil sample which is useful in the design of road pavement to be supported by the soil tested (ASTM D1833-73). The load is applied on the penetration piston which is penetrated into the soil sample at a constant penetration rate. The bearing ratio reported for the soil is normally the one at 0.1 inches (2.5 mm) penetration.

CAPABLE (fault) - Movement at or near the surface at least once in the past 35,000 years, and/or more than once in the past 500,000 years, (Nuclear Regulatory Commission).

CLOSED BASIN - A catchment area draining to some depression or lake within its area, from which water escapes only by evaporation.

GLOSSARY OF TERMS

COLLUVIAL DEPOSITS - A general term applied to any loose, heterogenous, and incoherent mass of soil material or rock fragments deposited chiefly by dislodgement and downslope transport of the material under the direct application of gravitational body stresses. Material is usually found at the base of a steep slope or cliff.

COMPACTION TEST - A type of test to determine the relationship between the moisture content and density of a soil sample which is prepared in compacted layers at various water contents (ASTM D1557-70).

COMPRESSIONAL WAVE -An elastic body wave in which particle motion is in the direction of propagation; the type of seismic wave assumed in conventional seismic exploration. Also called P-wave, dilatational wave, and longitudinal wave.

CONSOLIDATION TEST - A type of test to determine the compressibility of a soil sample. The sample is enclosed in the consolidometer which is then placed in the loading device. The load is applied in increments at certain time intervals and the change in thickness is recorded (See Appendix F for further details).

COARSE-GRAINED - A term which applies to a soil of which more than one-half of the soil particles, by weight, are larger than 0.075 mm in diameter (passing the No. 200 U.S. size seive).

COARSER-GRAINED - A term applied to alluvial fan deposits which are predominantly composed of material larger than 3 inches (76 mm) in diameter.

CORE SAMPLE - A cylindrical sample obtained with a rotating core barrel with a cutting bit at its lower end. Core samples are obtained in indurated deposits and in rock. (See Appendix F, Section F.2.3.6).

DEBRIS FLOW - A high-density flow of mud containing abundant coarse-grained materials (boulders, cobbles, gravel, sand) that frequently results from an unusually heavy rain.

DETECTOR - See GEOPHONE.

DIRECT SHEAR TEST - A type of test to measure the shear strength of a soil sample where the sample is forced to fail on a predetermined plane. (See Appendix F for further details).

GLOSSARY OF TERMS

DISSECTION/DISSECTED (alluvial fans) - The cutting of stream channels into the surface of an alluvial fan by the movement (or flow) of water.

DISTAL - That portion of an alluvial deposit farthest from its point of origin.

DRY UNIT WEIGHT/DRY DENSITY - Weight per unit volume of the solid particles in a soil mass.

ENTRENCH - The process whereby a stream erodes downward to form a trench.

EPHEMERAL(stream) - A stream in which water flow is discontinuous and of short duration.

EXTERNAL DRAINAGE - Stream drainage system whose downgradient flow is unrestricted by any topographic impediments.

EXTRUSIVE (rock) - Igneous rock that has been ejected onto the earth's surface (e.g., lava, basalt, rhyolite, andesite; detrital material, volcanic tuff, pumice).

FAULT - A plane or zone of rock fracture along which there has been displacement.

FAULT BLOCK MOUNTAINS - Mountains that are formed by normal faulting in which the surface crust is divided into structural, partially to entirely bounded fault blocks of different elevations.

FINE-GRAINED - A term which applies to a soil of which more than one-half of the soil particles, by weight, are smaller than 0.075 mm in diameter (passing the No. 200 U.S. size sieve).

FINER-GRAINED - A term applied to alluvial fan deposits, which are composed predominantly of material less than 3 inches (76 mm) in diameter.

FLOODING/LOW ENERGY FLOW - Flood waters flowing on a slope of low gradient.

FREE AIR ANOMALY - Gravity data which have been corrected for latitude and elevation (free air correction) but not for the density of rock between the datum and the plane of measurement (Bouguer correction).

GLOSSARY OF TERMS

FUGRO DRIVE SAMPLE - A 2.50 inch (6.4 cm) diameter soil sample obtained from a drill hole with a Fugro Drive Sampler. The Fugro drive sampler is a ring-lined barrel sampler containing 11 one-inch (2.54 cm) long brass sample rings. The sampler is advanced into the soil using a drop-hammer. (See Appendix F, Section F.2.3.3).

GAMMA - A unit of magnetic-field intensity. A gamma is 10^{-5} oersteds; sometimes expressed (incorrectly) as 10^{-5} gauss with which it is numerically equal.

GEOMORPHOLOGY - The study, classification, description, nature, origin, and development of present landforms and their relationships to underlying structures, and of the history of geologic changes as recorded by these surface features.

GEOPHONE - The instrument used to transform seismic energy into electrical voltage; a <u>seismometer</u>, <u>jug</u>, or <u>pick-up</u>.

GRAIN-SIZE ANALYSIS (GRADATION) - A type of test to determine the distribution of soil particle sizes in a given soil sample. The distribution of particle sizes larger than 0.075mm (retained on the No. 200 sieve) is determined by sieving, while the distribution of the particle sizes smaller than 0.075 mm is determined by a sedimentation process, using a hydrometer.

GRAVITY - The force of attraction between bodies because of their mass. Usually measured as the acceleration of gravity.

GRAVITY GRADIENT - The partial derivative of the acceleration of gravity with respect to distance in a particular direction, for which purpose the acceleration of gravity is considered as a scalar.

INTERIOR DRAINAGE - Stream drainage system that flows into a closed topographic low (basin).

INTRUSIVE (rock) - A rock formed by the process of emplacement of magma (liquid rock) in pre-existing rock. (e.g. granite, granodiorite, quartz monzonite).

LINE - A linear array of observation points, such as a seismic line.

LIQUID LIMIT - See ATTERBURG LIMITS.

LOW ENERGY FLOW - See FLOODING.

GLOSSARY OF TERMS

MAGNETIC INTENSITY - A vector quantity measuring magnetic field strength. The unit of magnetic intensity commonly used in geophysical exploration is the gamma (see GAMMA).

MANTLED PLAYA - A playa surface or a portion of the surface that is covered with younger geologic material such as windblown sand, or alluvium.

MILLIGAL - A unit of acceleration used with gravity measurements; 1 milligal = 10^{-5} m/sec.^{2}. Abbreviated mgal.

MOISTURE CONTENT - The ratio, expressed as a percentage, of the weight of water contained in a soil sample to the oven-dry weight of the sample.

N VALUE - Penetration resistance, number of blows required to drive the standard split spoon sampler for the second and third six inches (0.15 m) with a 140 pound (63.5 kg) hammer falling 30 inches (0.76 m) (ASTM D1586-67).

OVERBANK FLOODING - A large flow of water that overflows the sides of A stream channel.

"p-q" DIAGRAM - A convenient form to graphically present a large number of triaxial shear test results. It is defined as: $\frac{\sigma_1 + \sigma_3}{2}$ versus $\frac{\sigma_1 - \sigma_3}{2}$, where σ_1 is the maximum compressive stress at failure on the sample, and σ_3 is the confining pressure at failure.

PATINA - A dark coating or thin outer layer produced on the surface of a rock or other material by weathering after long exposure (e.g., desert varnish).

PAVEMENT/DESERT PAVEMENT - When loose material containing pebble-sized or larger rocks is exposed to rainfall and wind action the finer dust and sand are blown or washed away and the pebbles gradually accumulate on the surface, forming a mosaic which protects the underlying finer material from wind attack. Pavement can also develop in finer-grained materials. In this case the armored surface is formed by dissolution and cementation of the grains involved.

PEGAMATITE DIKE - A coarse grained igneous rock of granitic composition that forms as a tabular intrusion that cuts across the planar structures of the surrounding rock.

GLOSSARY OF TERMS

P-WAVE - See COMPRESSIONAL WAVE.

PERIMETER SEISMIC REFRACTION SURVEY - Shallow seismic refraction measurements made around the perimeter of a valley.

PERMEABLE - The ability of a geologic material to allow liquids to pass through it.

PICK-UP - See GEOPHONE.

PITCHER TUBE SAMPLE - An undisturbed, 2.87inch (73 mm) diameter soil sample obtained from a drill hole with a Pitcher tube sampler. The primary components of this sampler are an outer rotating core barrel with a bit and an inner stationary, spring-loaded, thin-wall sampling tube which leads or trails the outer barrel drilling bit, depending upon the hardness of the material being penetrated. (See Appendix V, Section F.2.3.5).

PLASTIC LIMIT - See ATTERBURG LIMITS.

PLASTICITY INDEX - See ATTERBURG LIMITS.

PLAYA/PLAYA DEPOSITS - A term used in the southwest U.S. for a dried-up, flat-floored area composed of thin, evenly stratified sheets of fine clay, silt, or sand, and representing the lowest part of a shallow, completely closed or undrained, desert lake basin in which water accumulates and is quickly evaporated, usually leaving deposits of soluble salts.

PONDING (of water) - The accumulating of water in a topographic depression.

PROXMIAL - That portion of an alluvial deposit nearest to its point of origin.

REGIONAL - The general attitude or configuration disregarding features smaller than a given size. The <u>regional gravity</u> is the gravity field produced by large scale variations ignoring anomalies of smaller size. See residualize.

RELATIVE AGE - The relationship in age (oldest to youngest) between geologic units without specific regard to numders of years.

RESIDUAL - What is left after a regional field has been removed, as in gravity or magnetic analysis. See RESIDULAIZE.

GLOSSARY OF TERMS

RESIDUALIZE - The process of separating a graphically depicted curve or a surface into it low-frequency parts (called the regional) and its high-frequency parts (called the residual). Residualizing is an attempt to sort out of the total field those anomalies which result from local structure; that is, to do fine local anomalies by subtracting gross (regional) effects.

ROCK UNITS - Distinct rock mmasses with different characteristics (e.g., igneous, metamorphic, sedimentary).

S-WAVE - See SHEAR WAVE.

SAND DUNE - A low ridge or hill consisting of loose sand deposited by the wind, found in various desert and coastal regions and generally where there is abundant surface sand.

SEISMIC - Having to do with elastic waves. Energy may be transmitted through the body of an elastic solid as P-waves (compressional waves) or S-waves(shear waves).

SEISMIC REFRACTION DATA: deep/shallow - Data derived from a type of seismic shooting based on the measurement of seismic energy as a function of time after the shot and of distance from the shot, by determining the arrival times of seismic waves which have travelled nearly parallel to the bedding in high-velocity layers, in order to map the depth to such layers.

SEISMOGRAM - A seismic record.

SEISMOMETER - See GEOPHONE.

SHEAR WAVE - A body wave in which the particle motion is perpendicular to the direction of propagation. Also called S-Wave or transverse wave.

SHEETFLOODING - A process in which storm-borne water spreads as a thin, continuous veneer (sheet) over a large area.

SHEET SAND - A blanket deposit of sand which accumulates in shallow depressions or against rock outcrops, but does not have characteristic dune form.

SHOT - Any source of seismic energy; e.g., the detonation of an explosive.

SHOT POINT - The location of any source of seismic energy; e.g., the location where an explosive charge is detonated in one hole or in a pattern of holes to generate seismic energy. Abbreviated SP.

GLOSSARY OF TERMS

SPECIFIC GRAVITY - The ratio of the weight in air of a given volume of soil solids at a stated temperature to the weight in air of an equal volume of distilled water at a stated temperature.

SPLIT SPOON SAMPLE - A disturbed sample obtained with a split spoon sampler with an outside diameter of 2.0 inches (5.1 cm). The sample consists of a split barrel which is driven into the soil using a drop-hammer. (See Appendix F, Section D.2.3.4, and ASTM D1586-67).

SPREAD - The layout of geophone groups from which data from a single shot are recorded simultaneously. Spreads containing twenty-four geophones have been used in Fugro's seismic refraction surveys.

STREAM CHANNEL DEPOSITS - Materials (clay, silt, sand, gravel, cobbles, boulders) which have been deposited in a stream channel.

SURFICIAL DEPOSIT - Unconsolidated and residual and alluvial deposits occurring on or near the Earth's surface.

TRANSITORY - A poorly defined, shallow ephemeral stream across an alluvial fan surface, the position of which is temporary and tends to shift frequently.

TRIAXIAL SHEAR - A type of test to measure the shear strength of an undisturbed soil sample. (See Appendix F for further details).

UNCONFINED COMPRESSION - A type of test to measure the compressive strength of an undisturbed soil sample. (See Appendix F for further details).

UNIFIED SOIL CLASSIFICATION SYSTEM (U.S.C.S.) - A system which determines soil classification on the basis of grain-size distribution and Atterburg Limits. (See Figures A through C).

VALLEY SEISMIC REFRACTION SURVEY - Deep seismic refraction measurements made near the middle of a valley to determine seismic wave propagation velocities and thickness of valley fill.

VELOCITY - Refers to the propagation rate of a seismic wave without implying any direction. Velocity is a property of the medium and not a vector quantity when used in this sense.

VELOCITY LAYER - A layer of rock or soil with a homogenous seismic velocity.

GLOSSARY OF TERMS

VELOCITY PROFILE - A cross-section showing the distribution of material seismic velocities as a function of depth and its configuration.

WASH SAMPLE - A sample obtained by screening the returned drilling fluid during rotary wash drilling to obtain lithologic information between samples. (See Appendix F, Section F.2.3.7).

Definitions were derived in part from Webster's New Collegiate Dictionary (1972 edition), Glossary of Geology (American Geological Institute, 1972), and Encyclopedic Dictionary of Exploration Geophysics (Sheriff, 1973).

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AD-A113 447 FUGRO NATIONAL INC LONG BEACH CA F/G 8/7
MX SITING INVESTIGATION. GEOTECHNICAL EVALUATION OF LUKE BOMBIN--ETC(U)
JAN 78 F04704-77-C-0010
UNCLASSIFIED FN-TR-19D-VOL-1 NL

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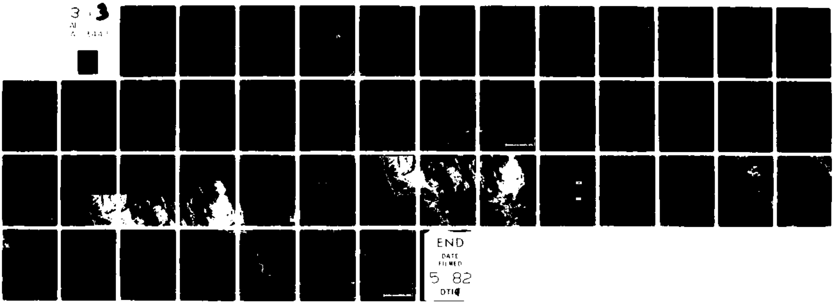

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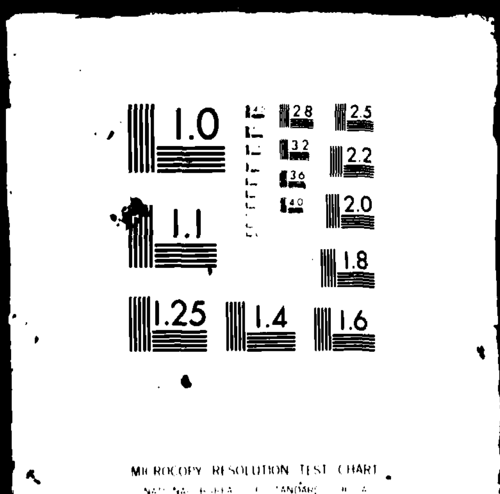

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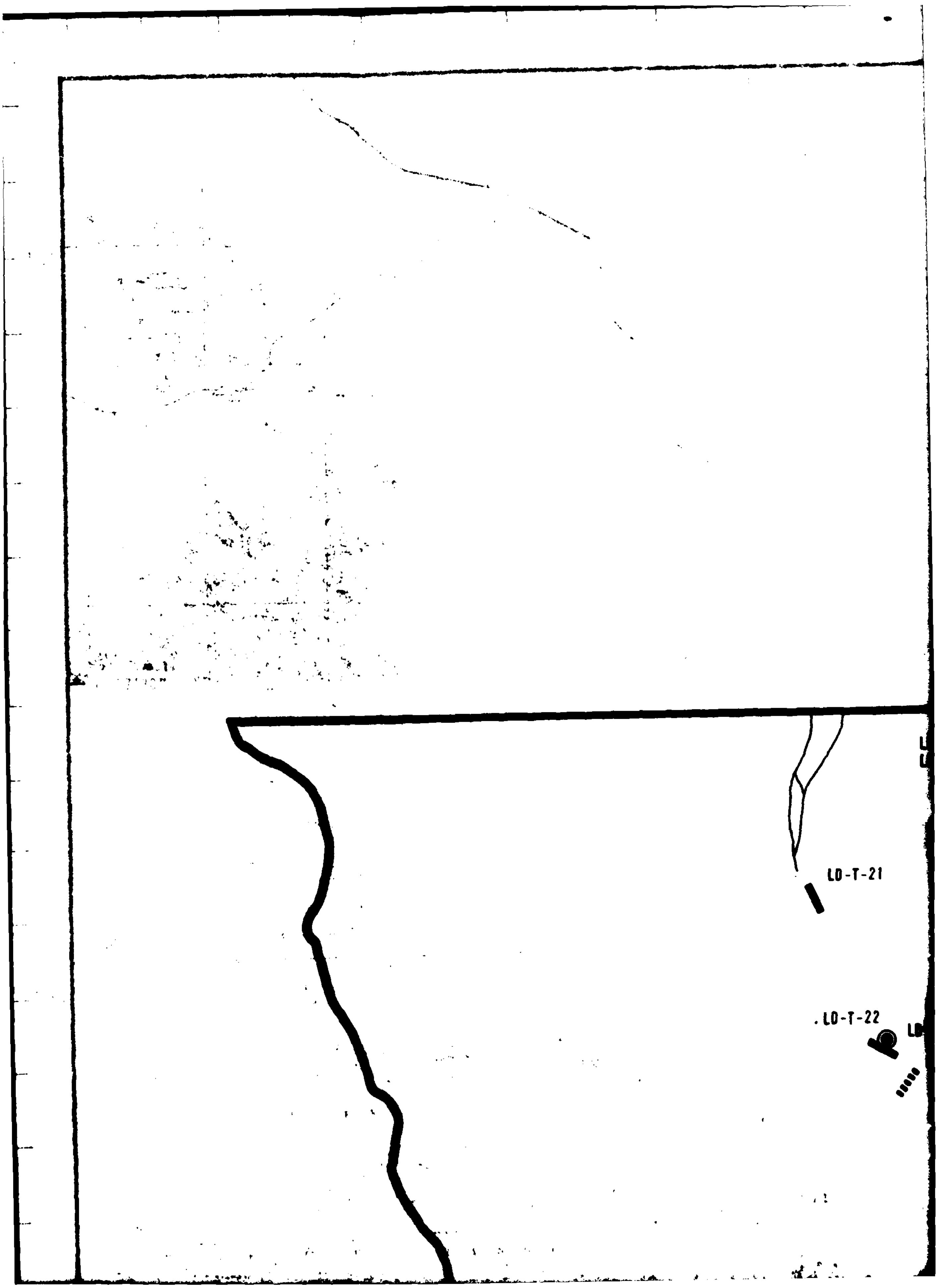

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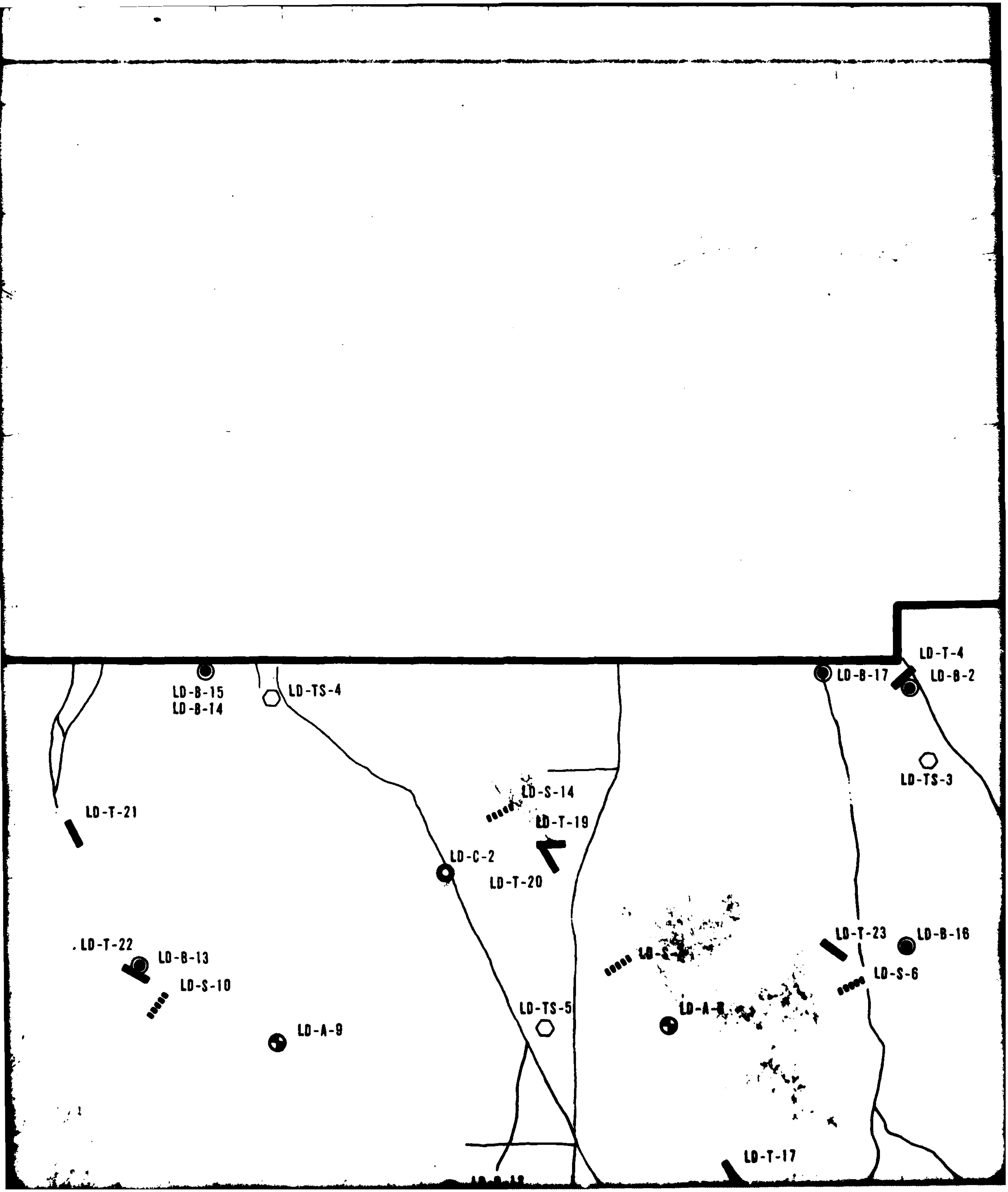
LD-T-22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LD-T-19
LD-C-2
LD-T-20
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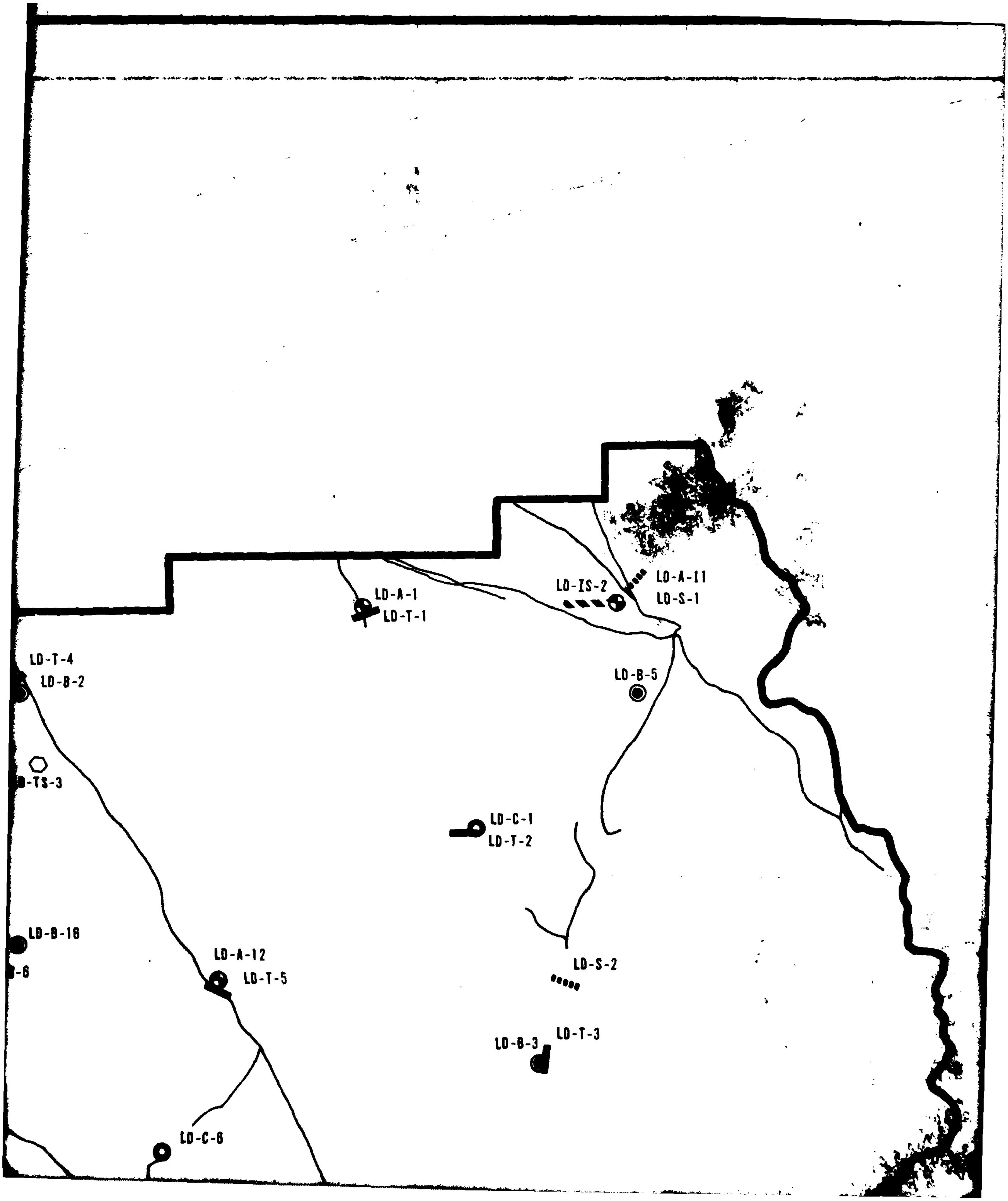
LD-T-17



LD-A-11
LD-IS-2
LD-S-1
LD-A-1
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LD-T-4
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LD-C-1
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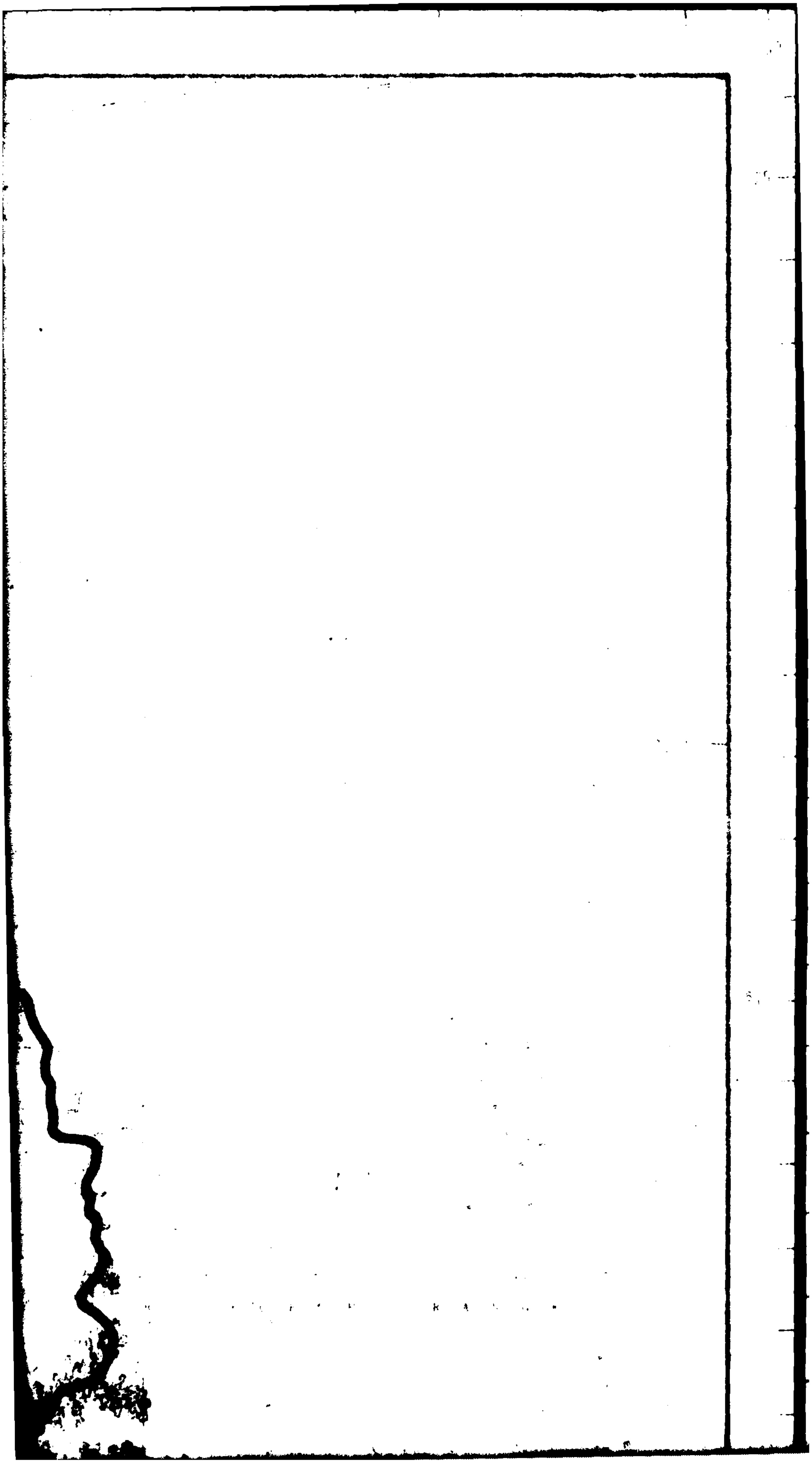
LD-C-6



EXPLANATION

BORINGS AND TRENCHES

LD-A-1 — A-Boring to a nominal depth of 50 feet (15.2 meters)

LD-B-1 — B-Boring to a nominal depth of 100 feet (30.5 meters)

LD-C-1 — C-Boring to a nominal depth of 300 feet (91.4 meters)

LD-D-1 — D-Boring to a nominal depth of 1000 feet (304.8 meters)

LD-T-1 — Trench (not to scale)

SEISMIC REFRACTION LINES

LD-DS-1 — Deep Seismic Refraction Line

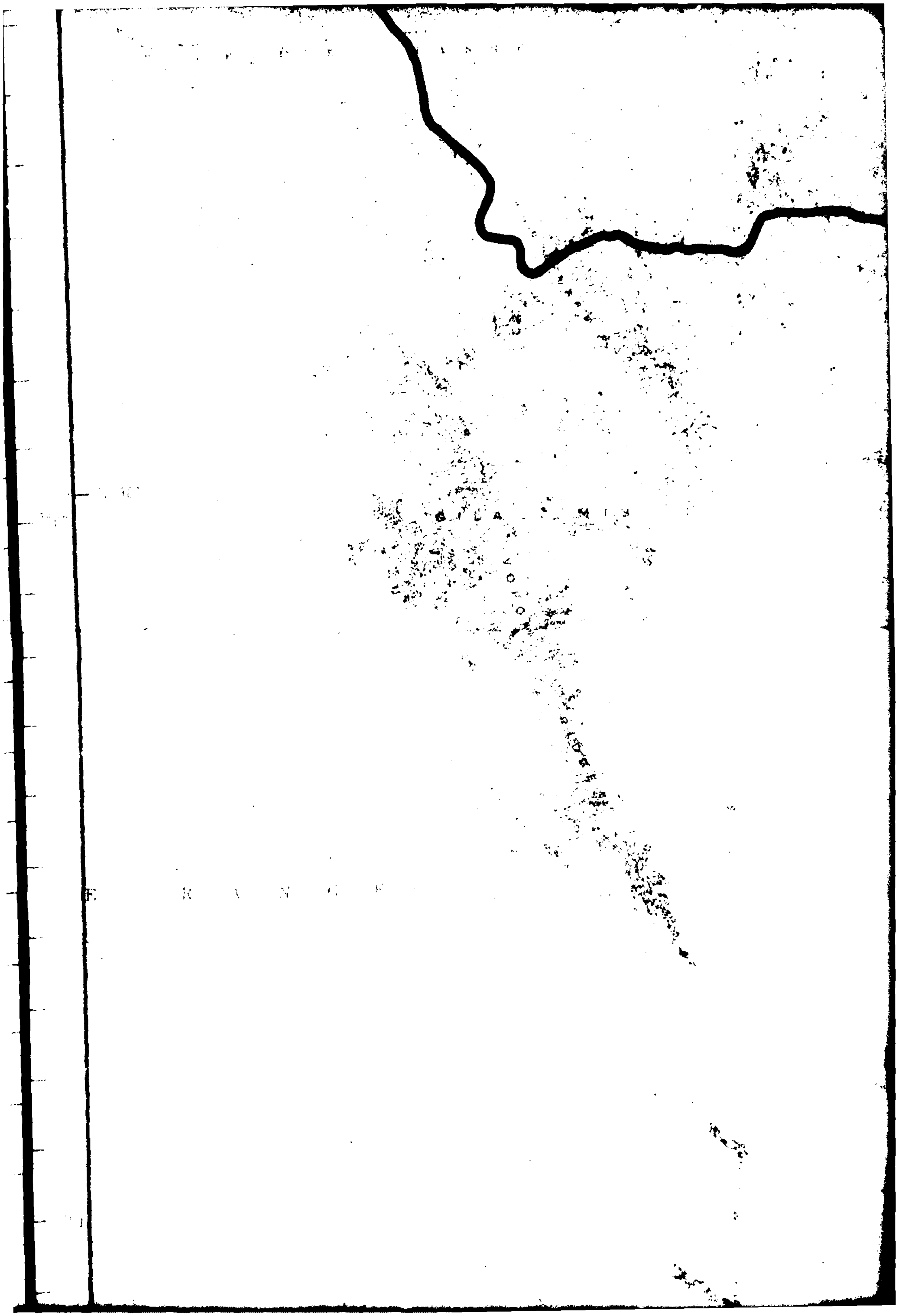
LD-IS-1 — Intermediate Seismic Refraction Line

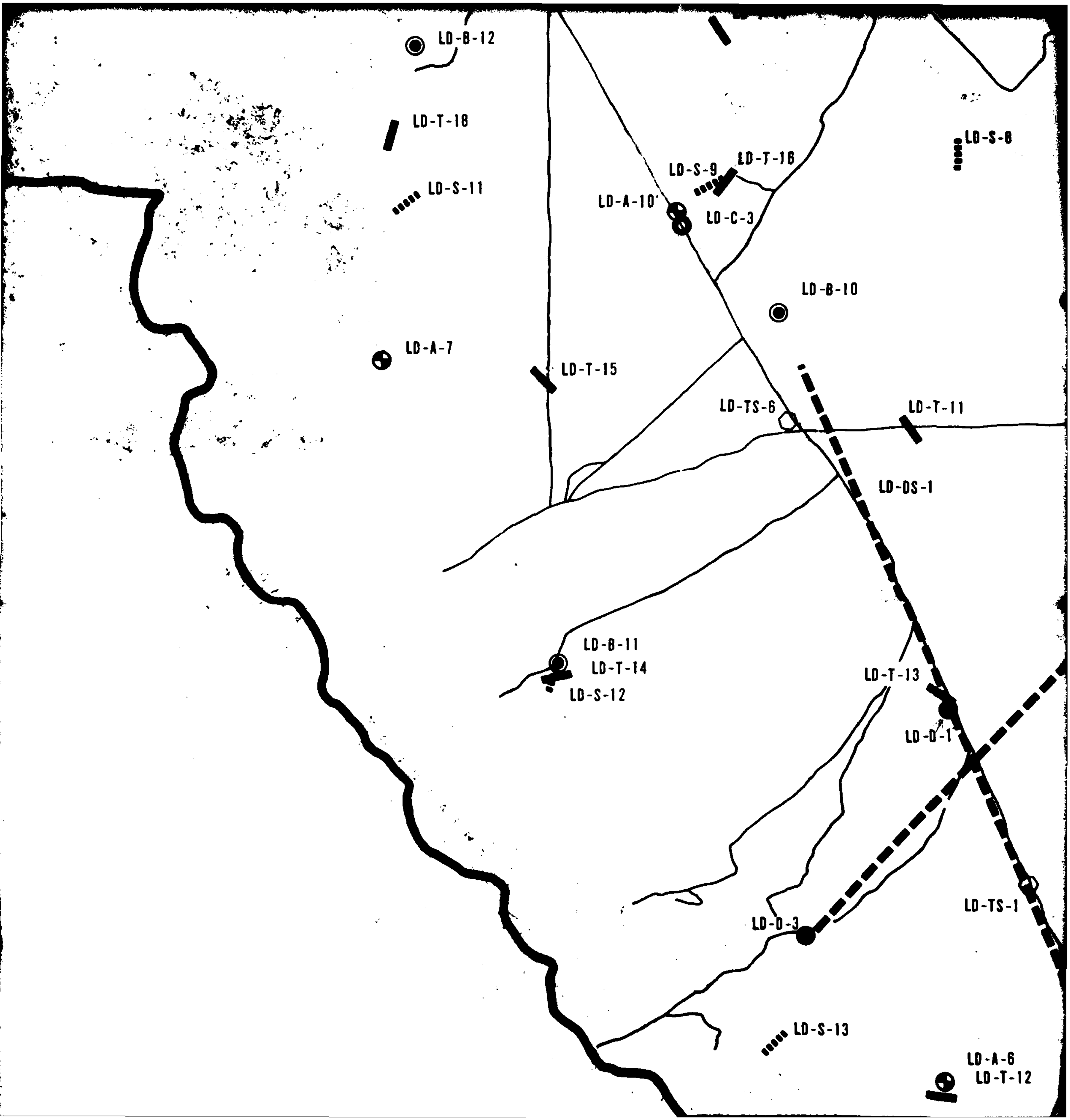
LD-S-1 — Shallow Seismic Refraction Line

MISCELLANEOUS

LD-TS-1 — Transponder Remote Tower

Existing Roads

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LD-A-7
LD-T-15
LD-TS-6
LD-T-11
LD-DS-1
LD-B-11
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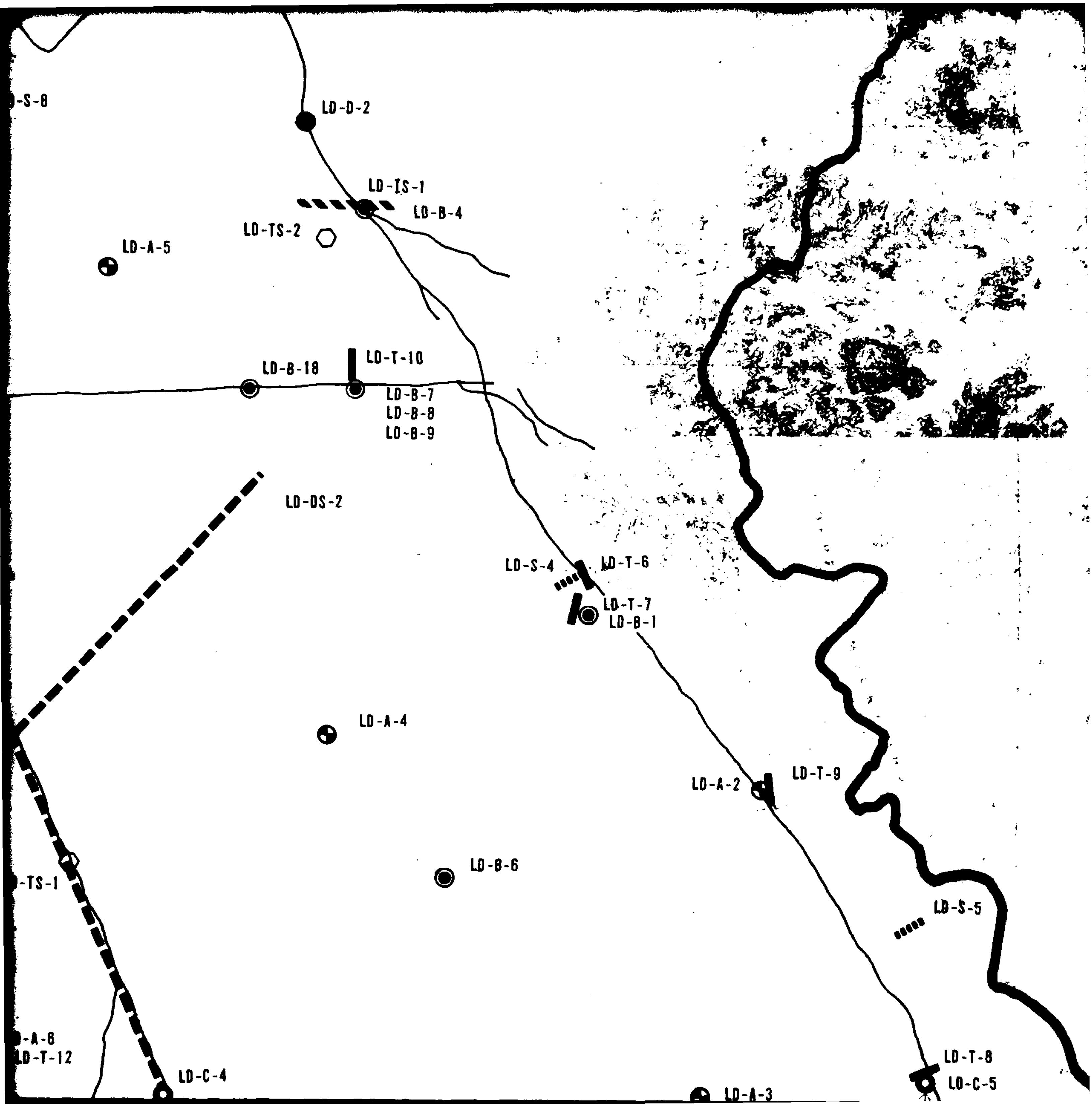
LD-T-12



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LD-A-2
LD-T-9
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LD-B-6
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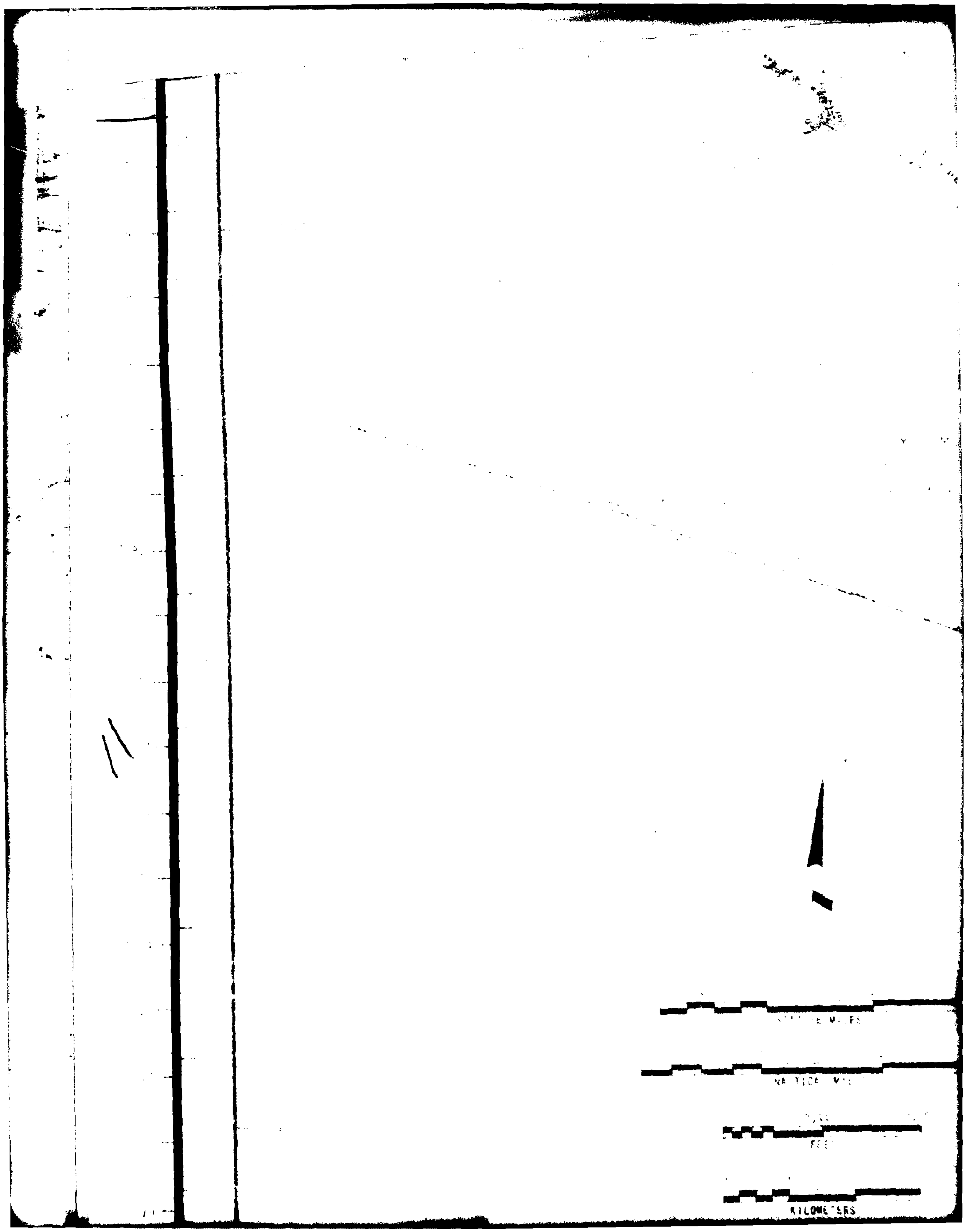
LD

Transponder Remote Tower

Existing Roads

10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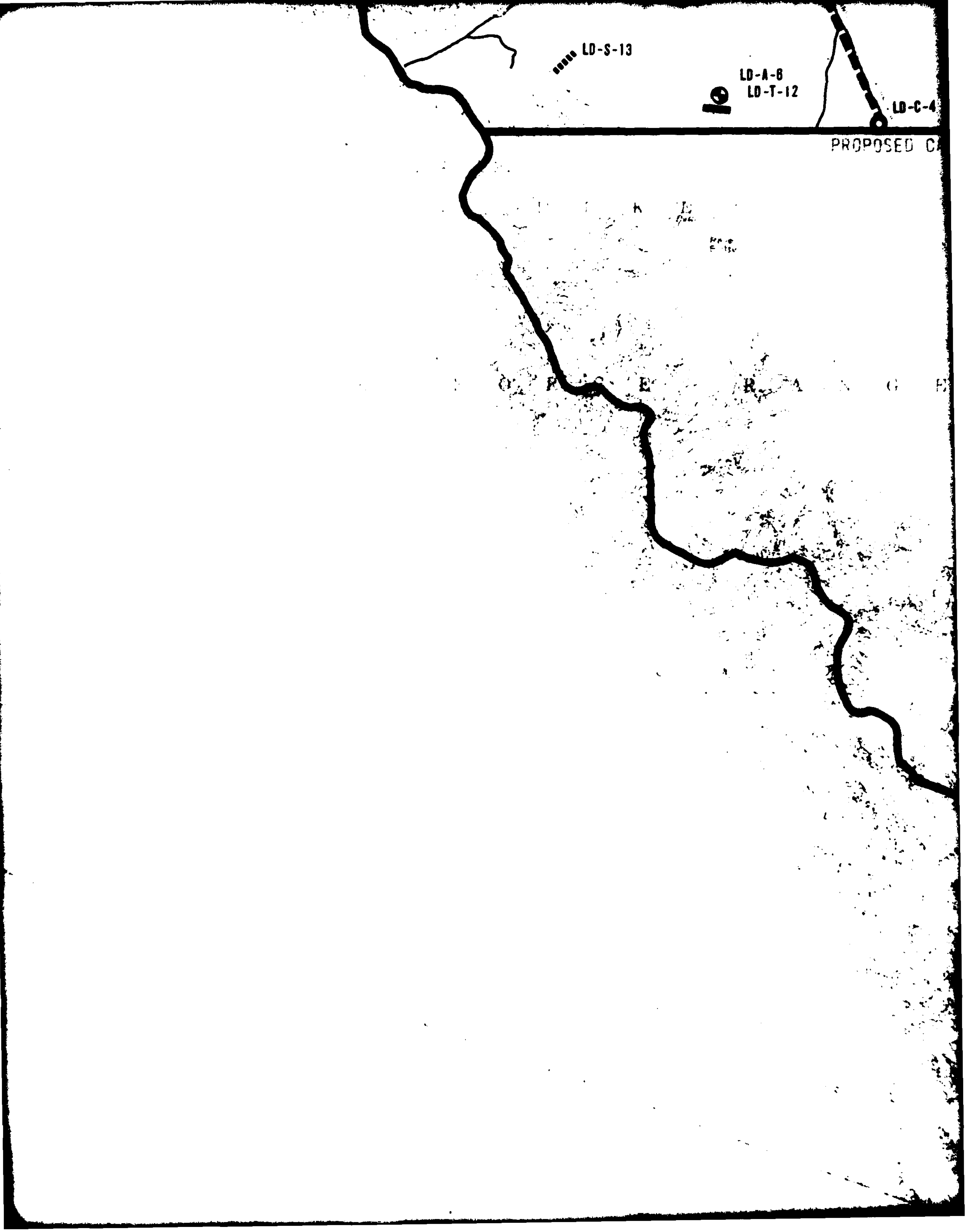
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LD-A-6
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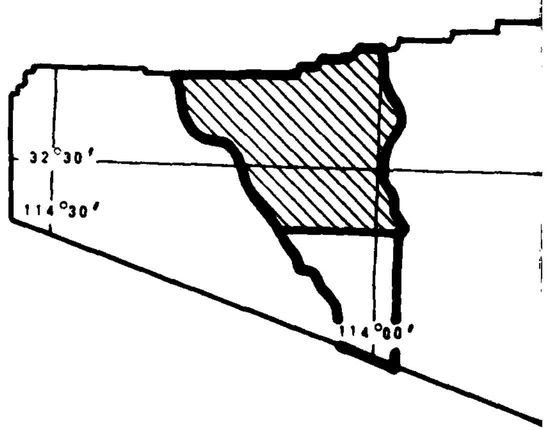
LD-C-4
PROPOSED C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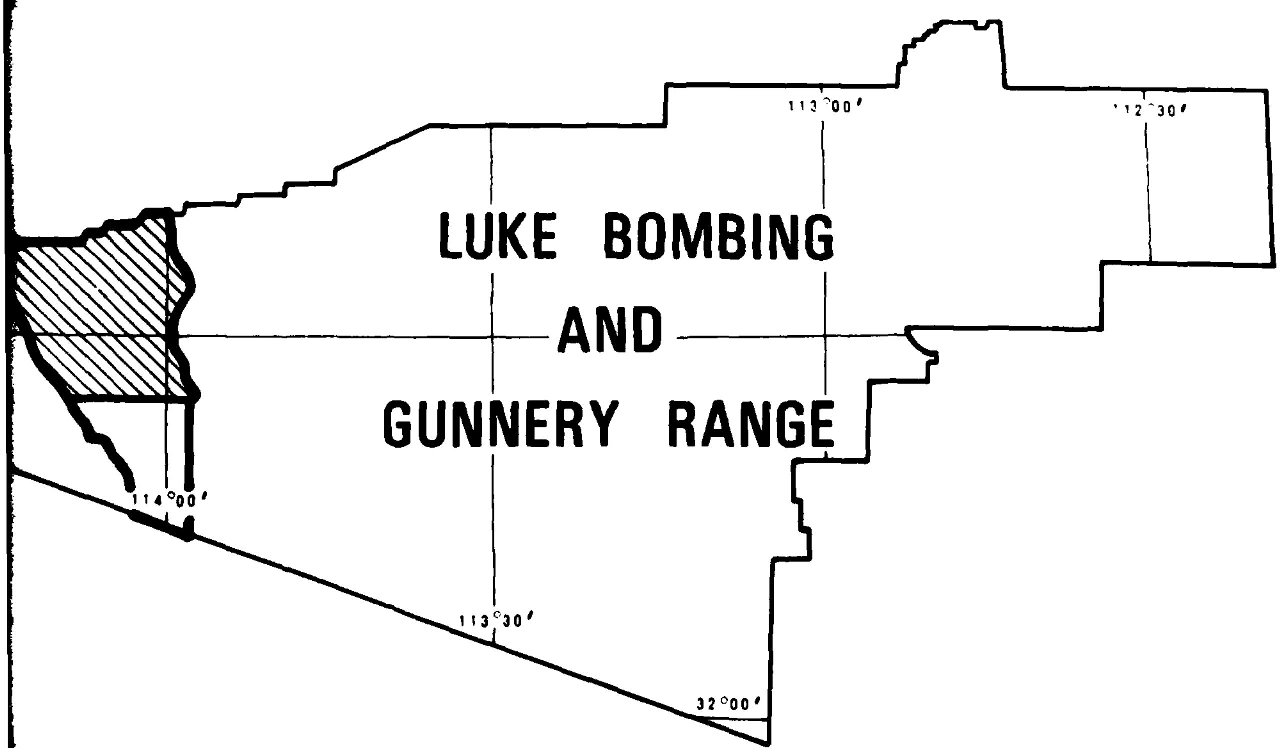
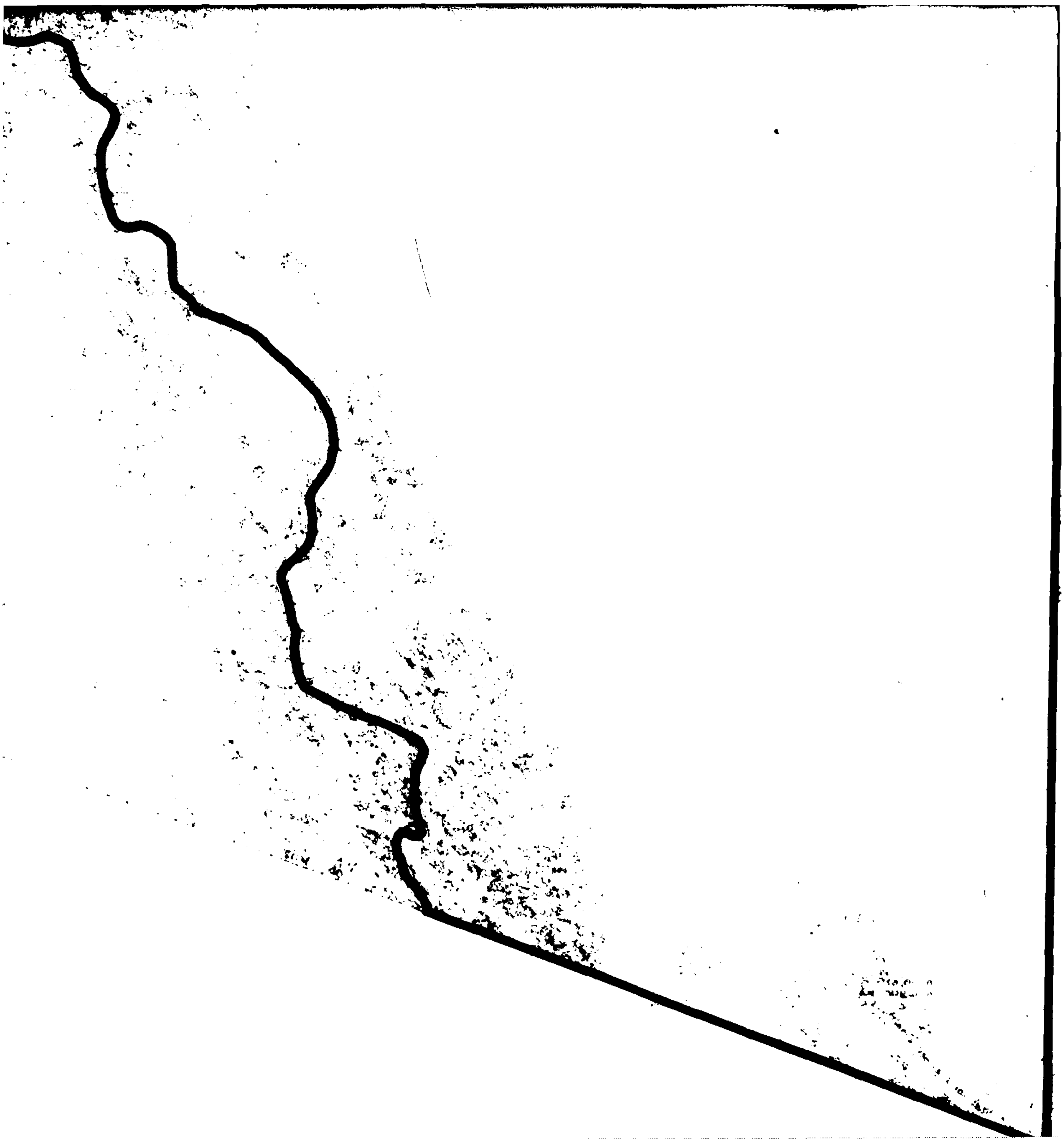
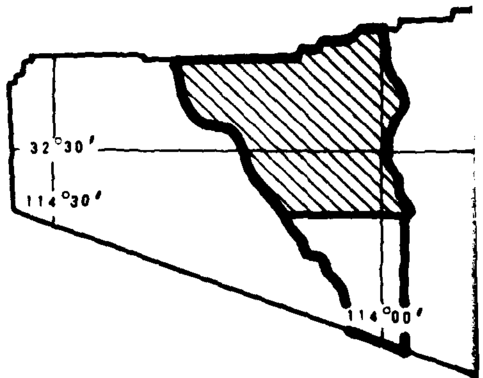
114°00′



LUKE BOMBING
AND
GUNNERY RANGE
113°00′
112°30′
114°00′
113°30′
32°00′

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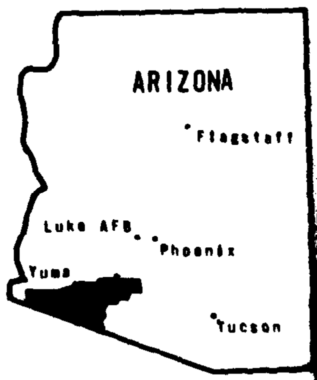
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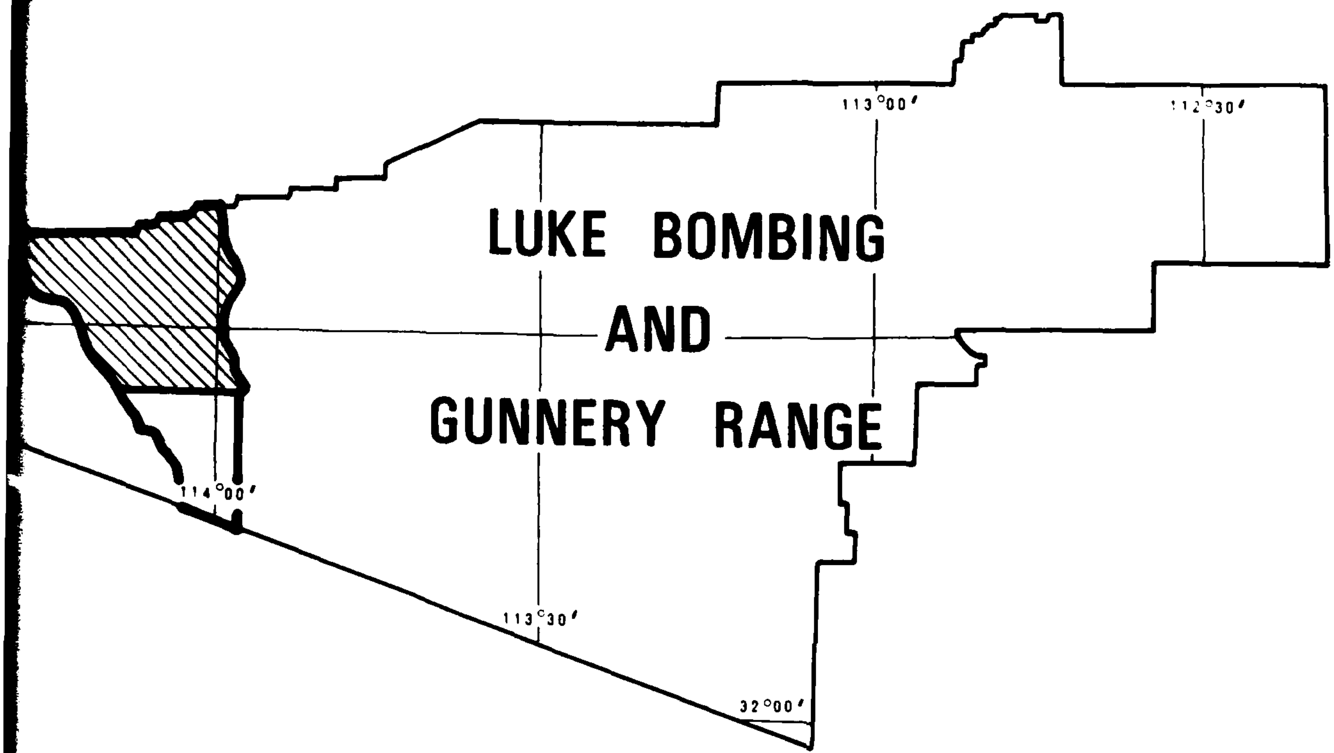
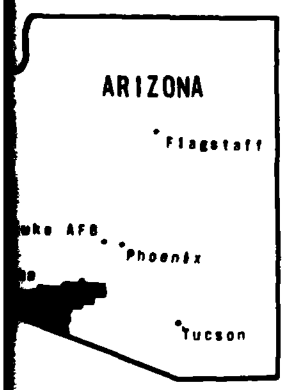
Luke AFB
Phoenix
Yuma
Tucson





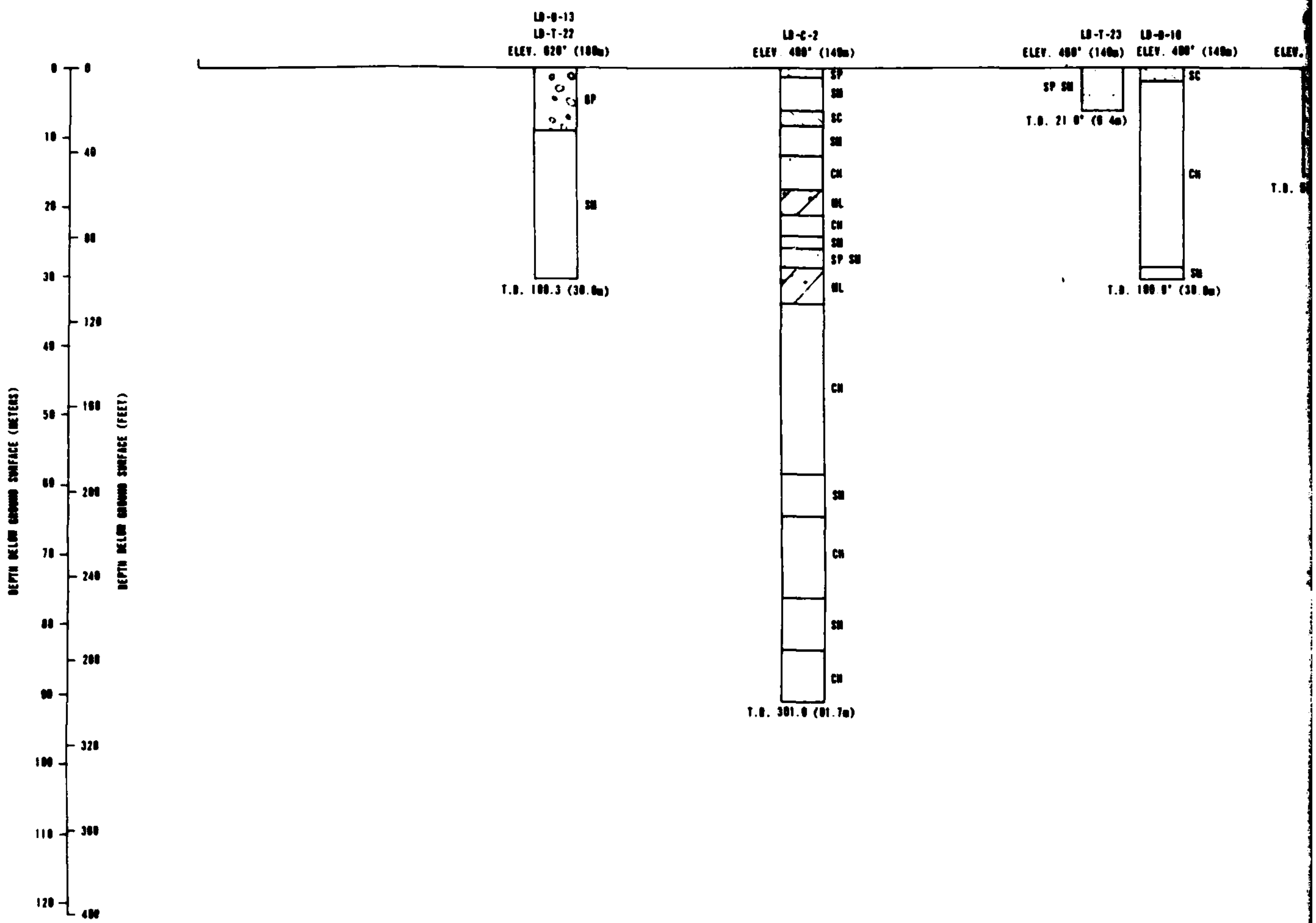
ACTIVITIES LOCATION MAP
LECHUGUILLA DESERT, ARIZONA

MX SITING INVESTIGATION
DEPARTMENT OF THE AIR FORCE - SAMSO

DRAWING
1

FUGRO NATIONAL, INC.

SOIL PROFILE LD-SP-AA'



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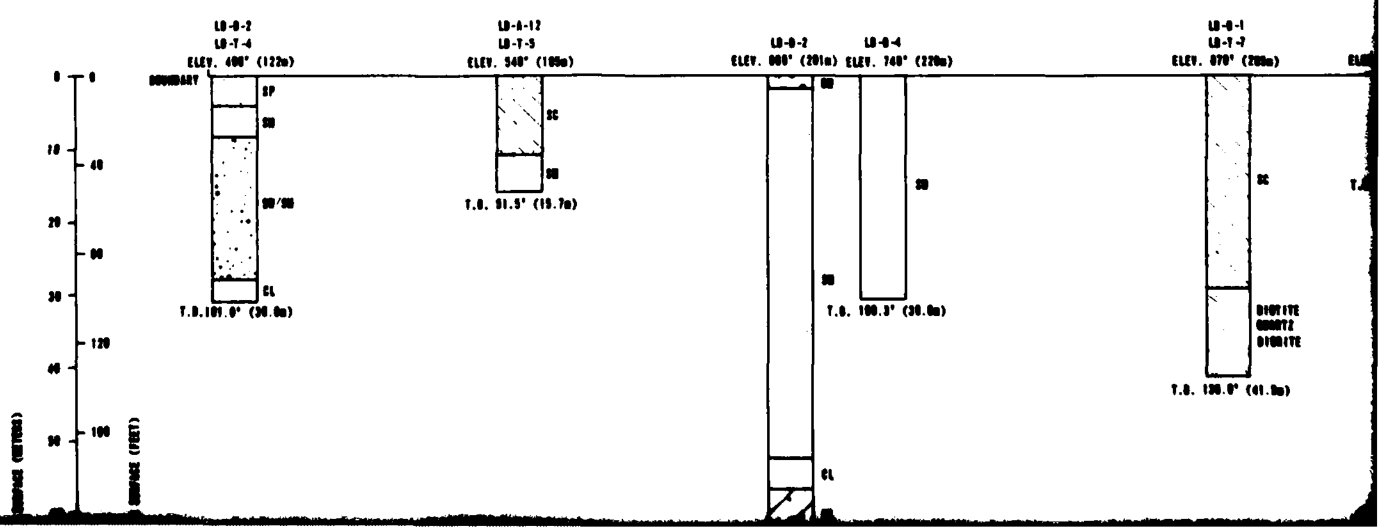
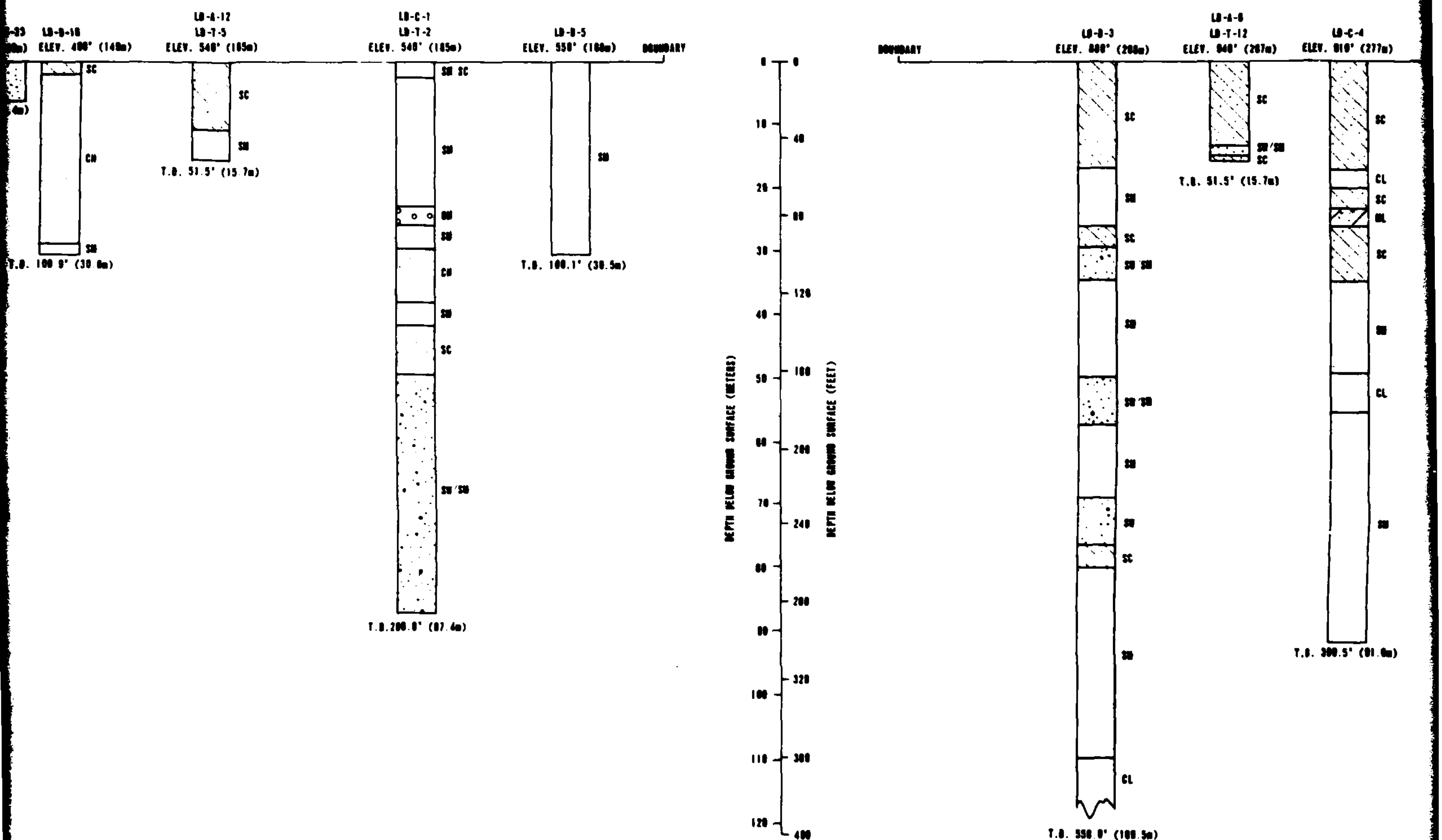
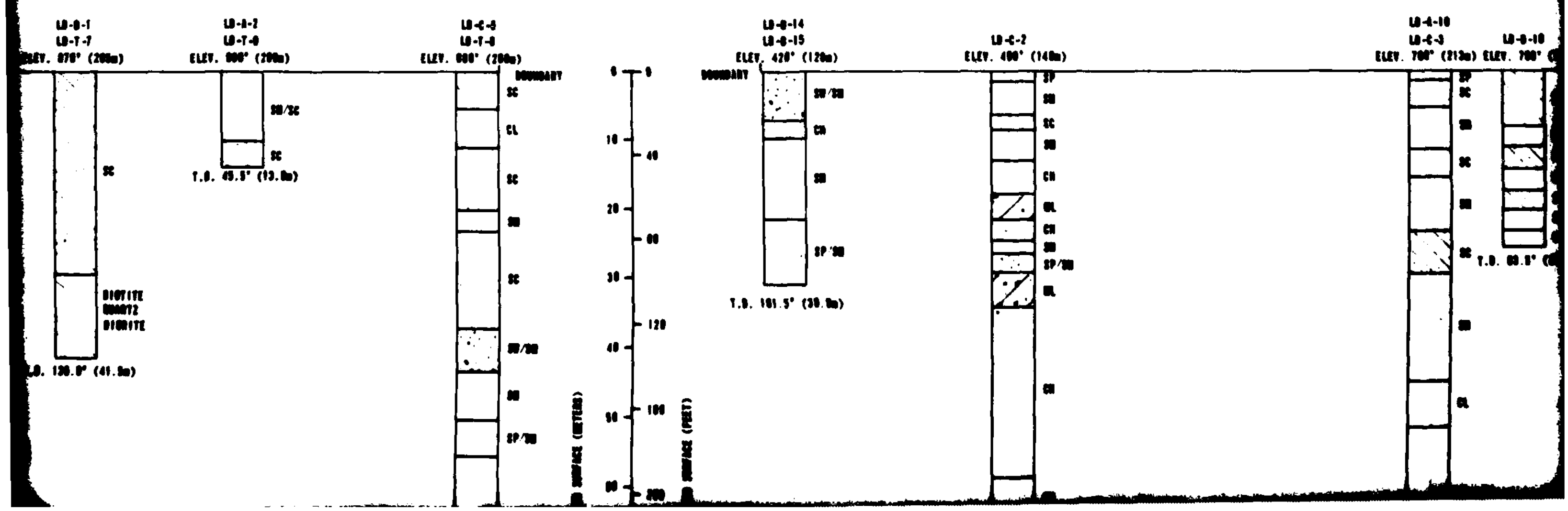


P-AA'

SOIL PR



SOIL PROFILE LD-



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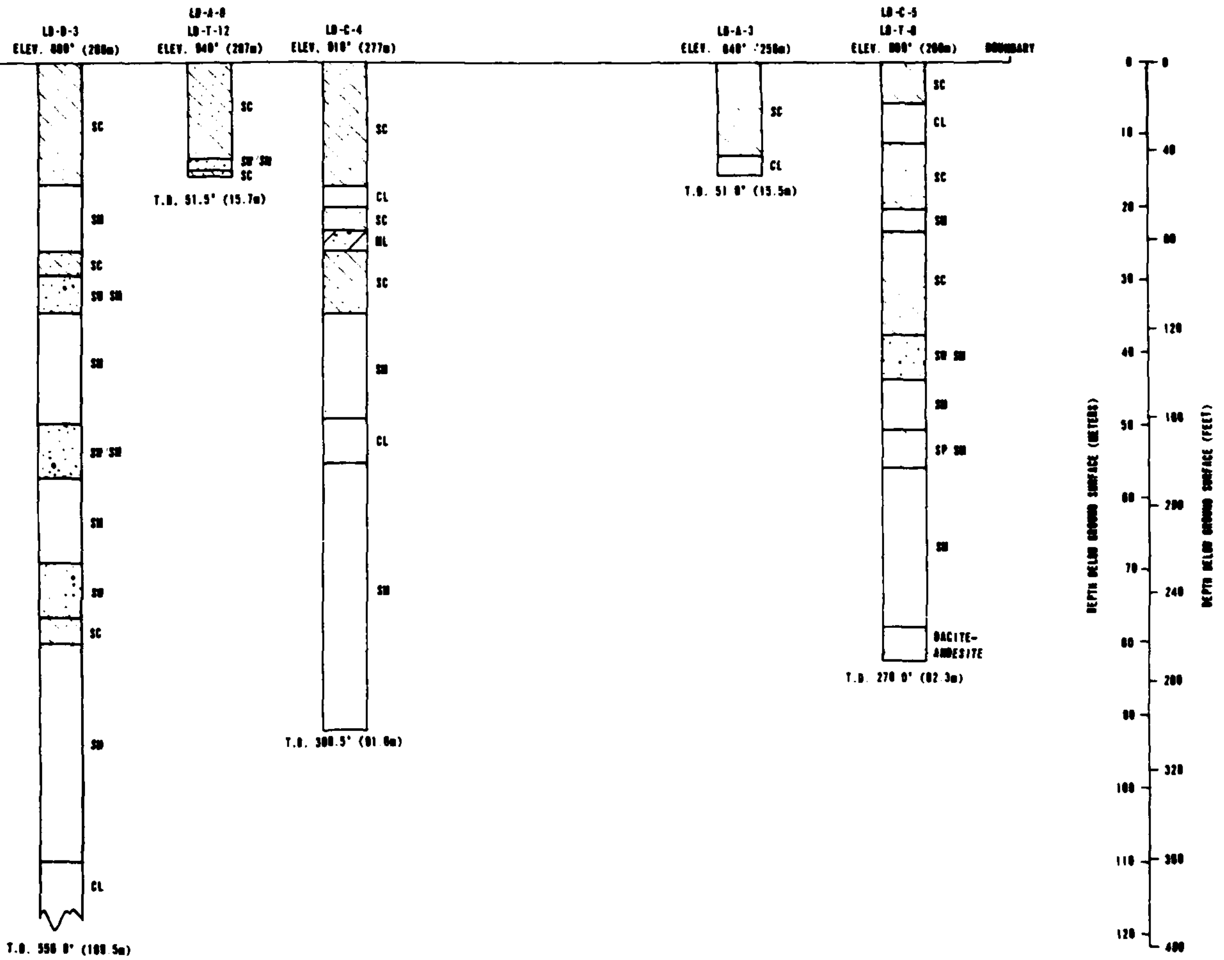

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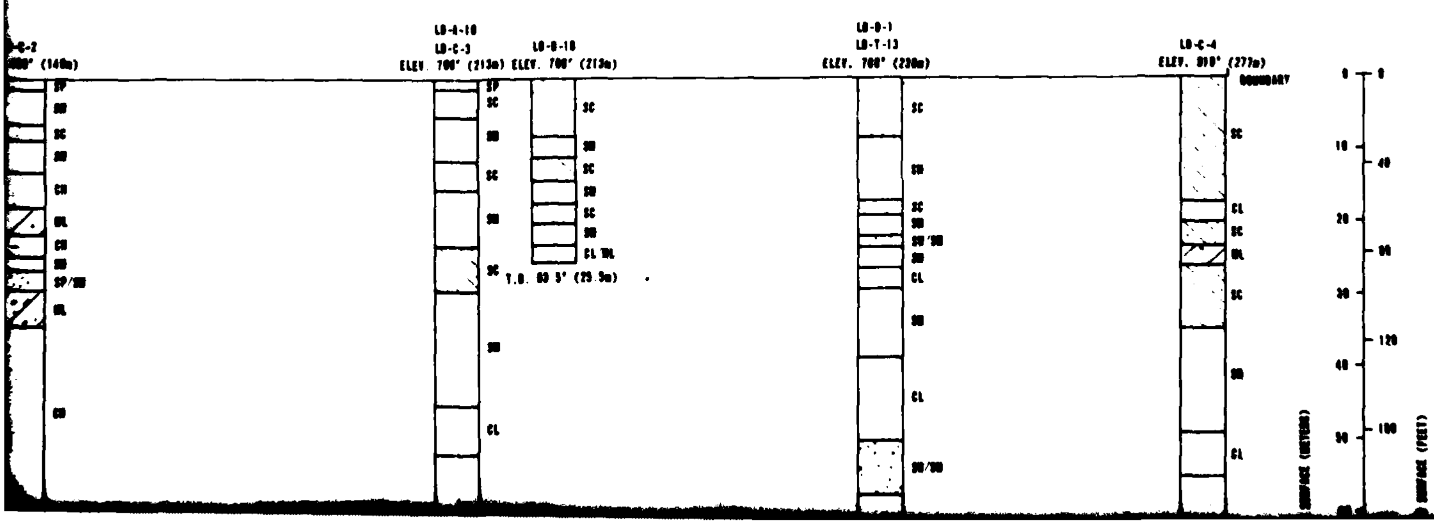
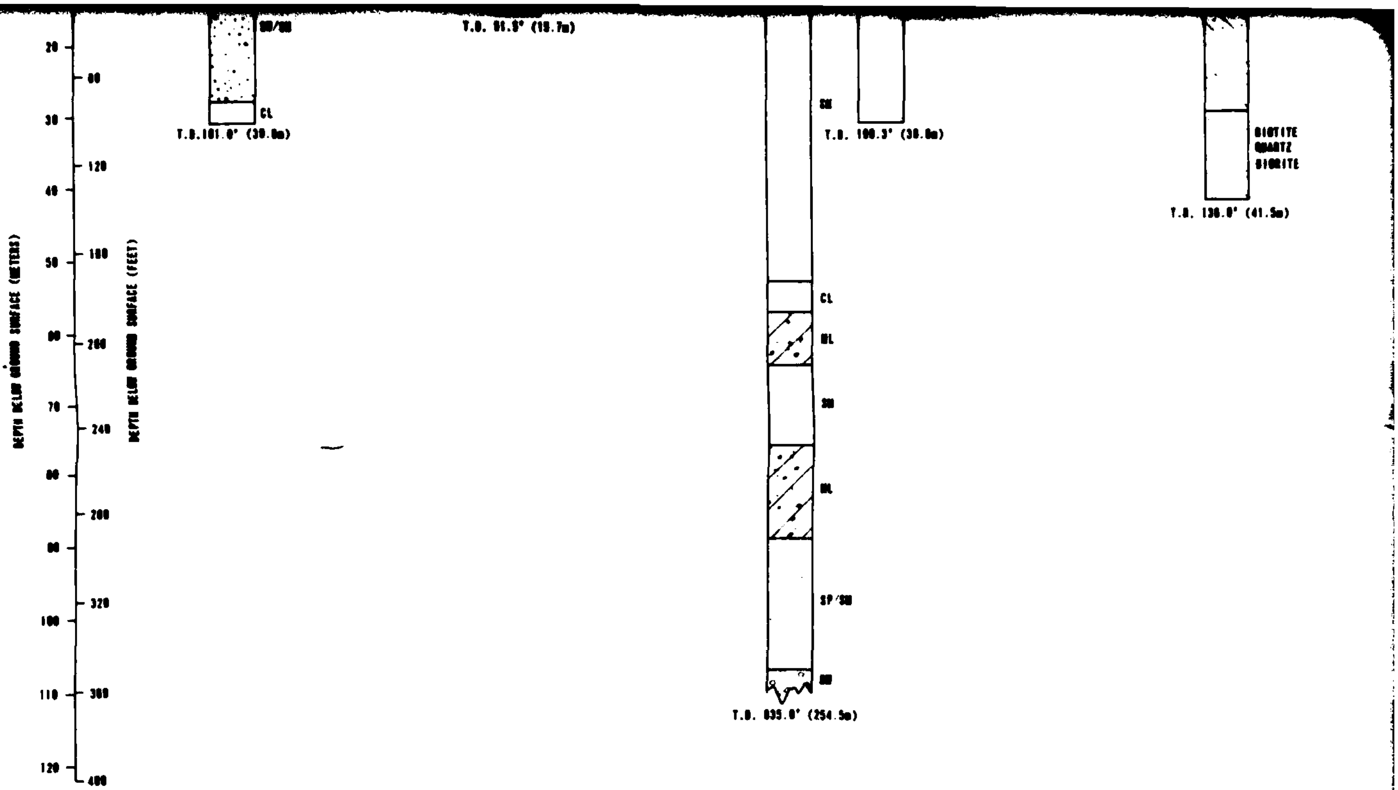
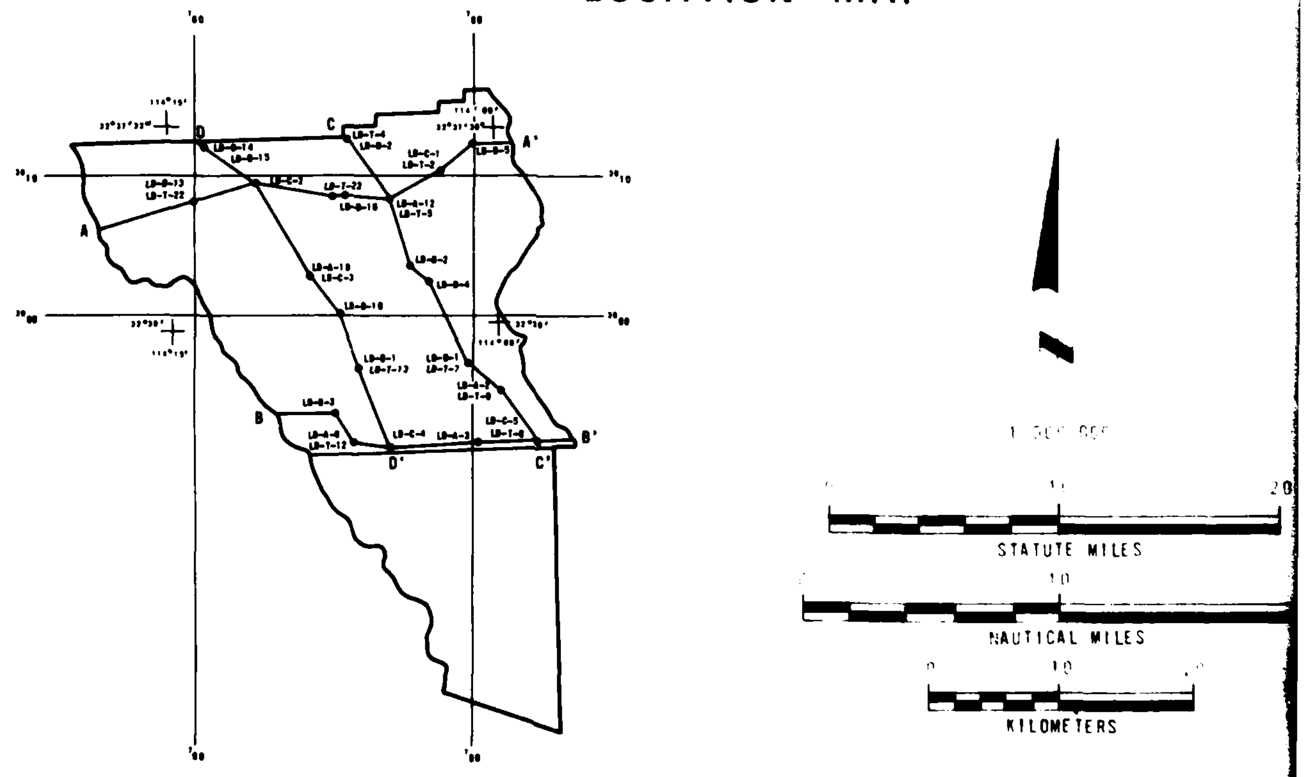




LOCATION MAP



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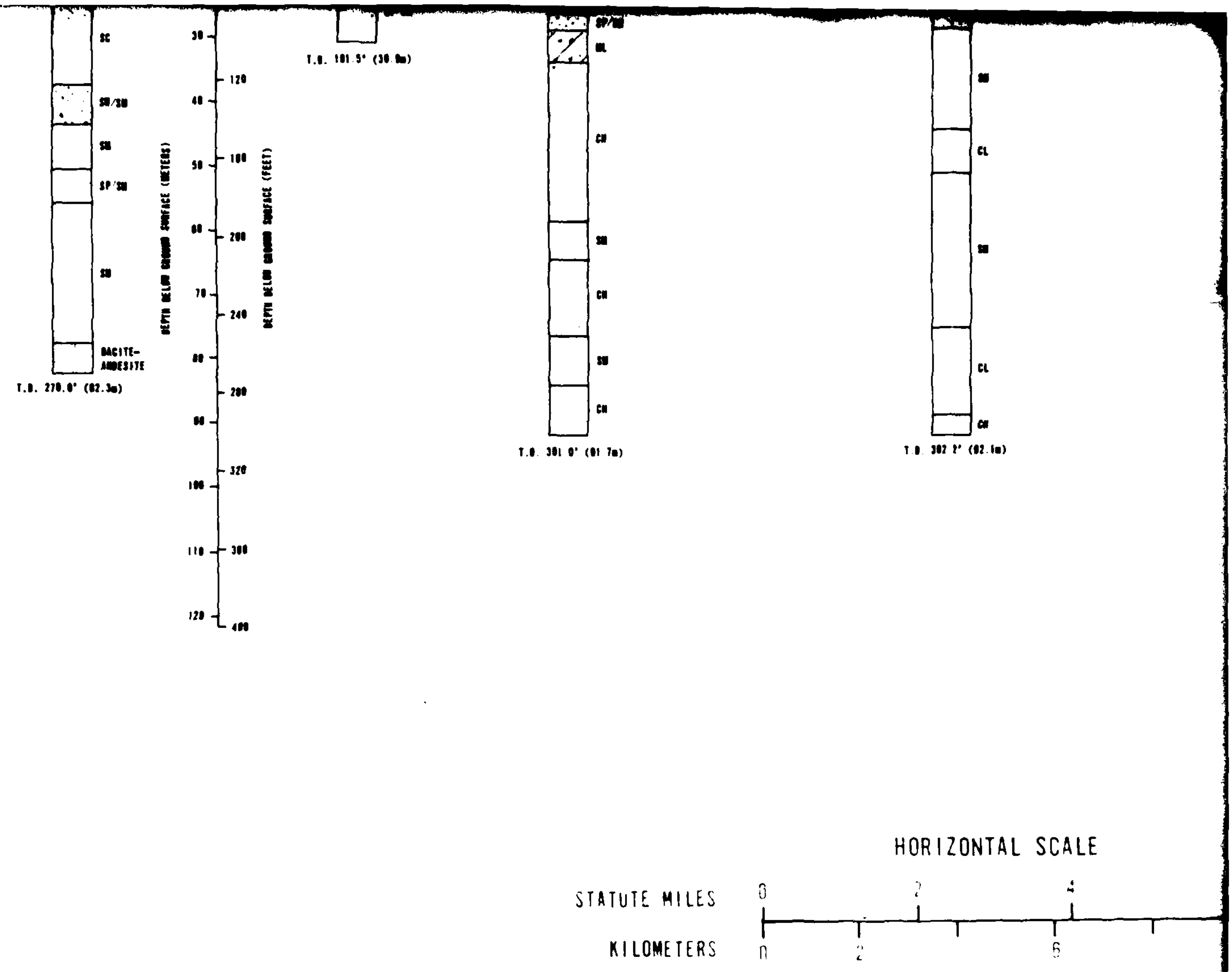
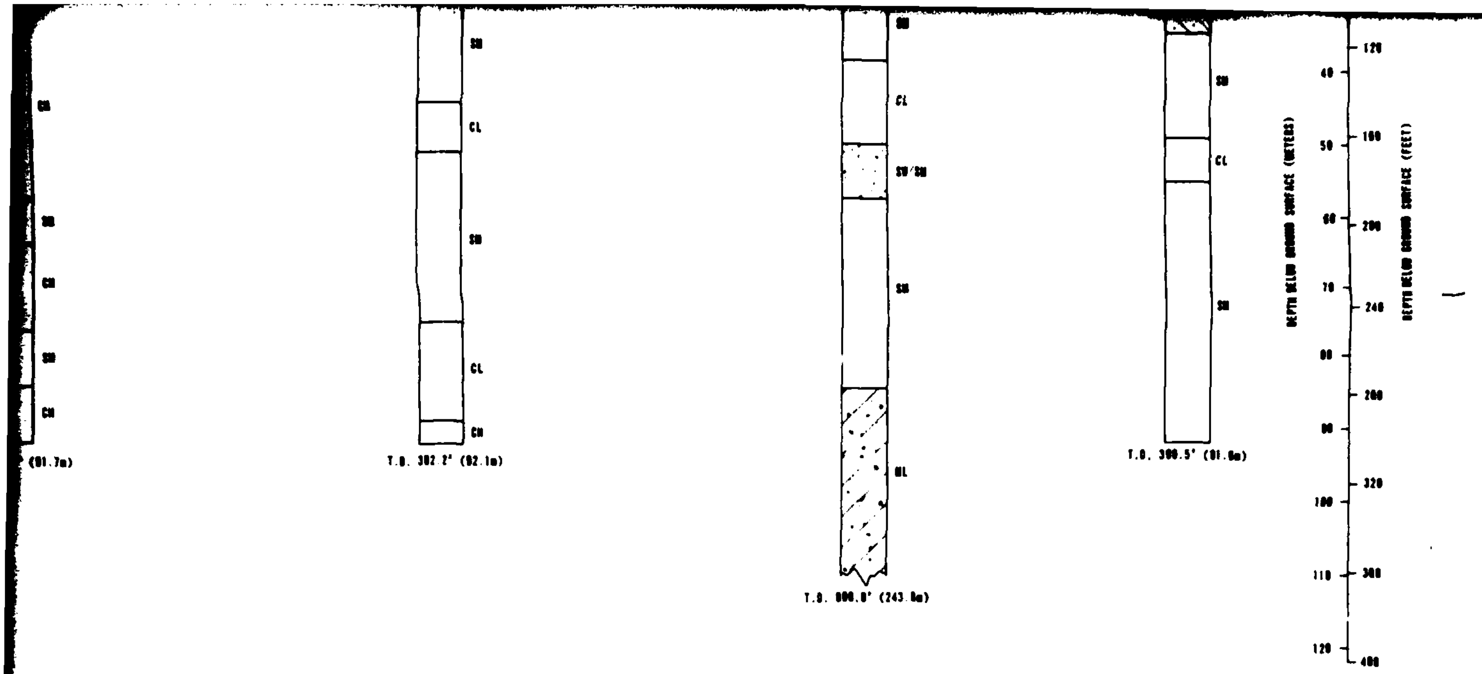
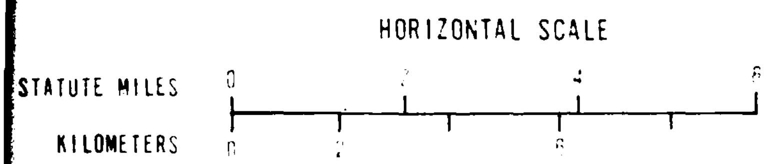

SC
DACITE-
ANDESITE
T.D. 270.0' (82.3m)
DEPTH BELOW GROUND SURFACE (METERS)
30
40
50
60
70
80
90
100
110
120
DEPTH BELOW GROUND SURFACE (FEET)
120
160
200
240
280
320
360
400
T.D. 101.5' (30.9m)
CL
T.D. 301.0' (91.7m)
T.D. 302.2' (92.1m)
HORIZONTAL SCALE
STATUTE MILES
0
2
4
KILOMETERS
0
2
6

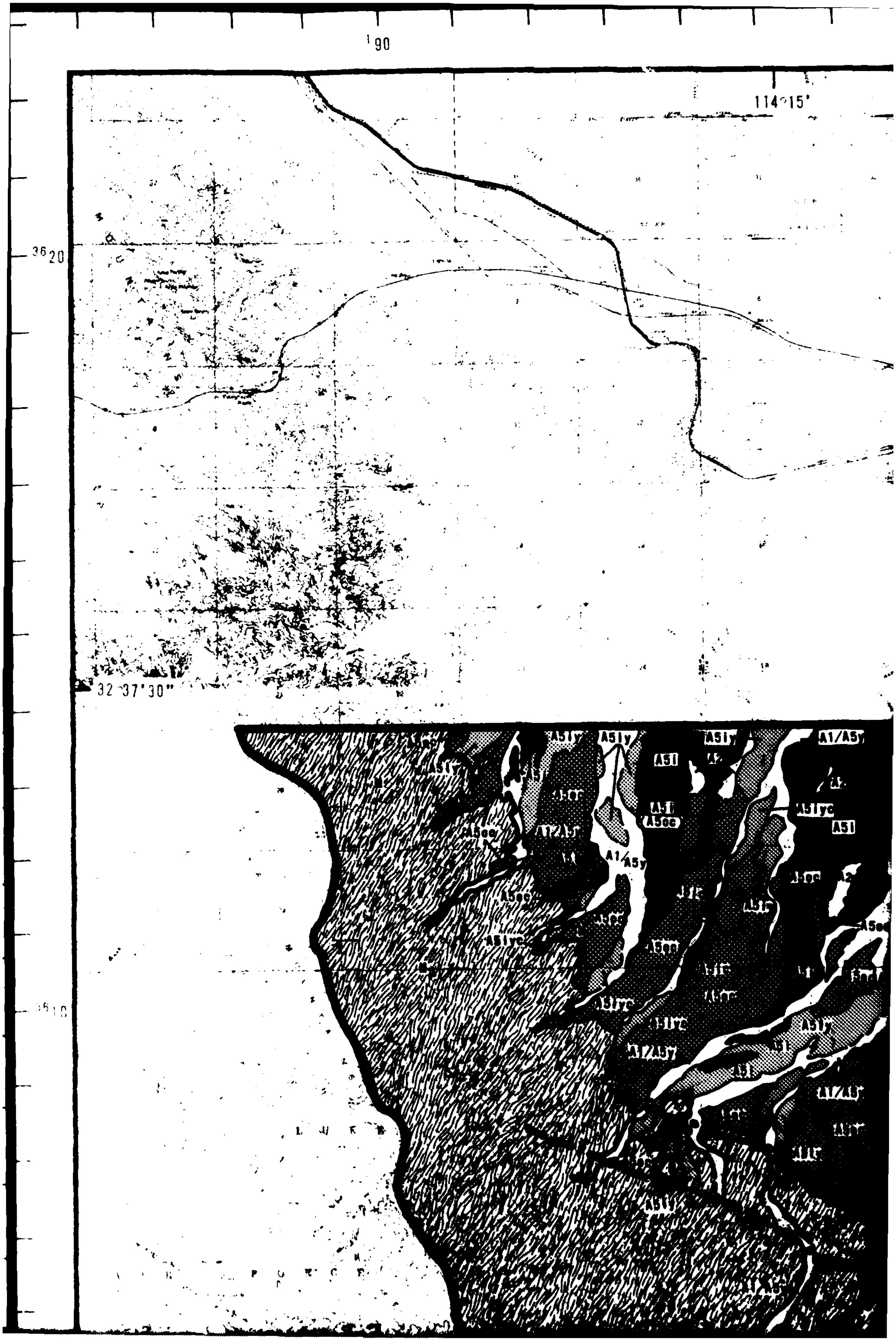




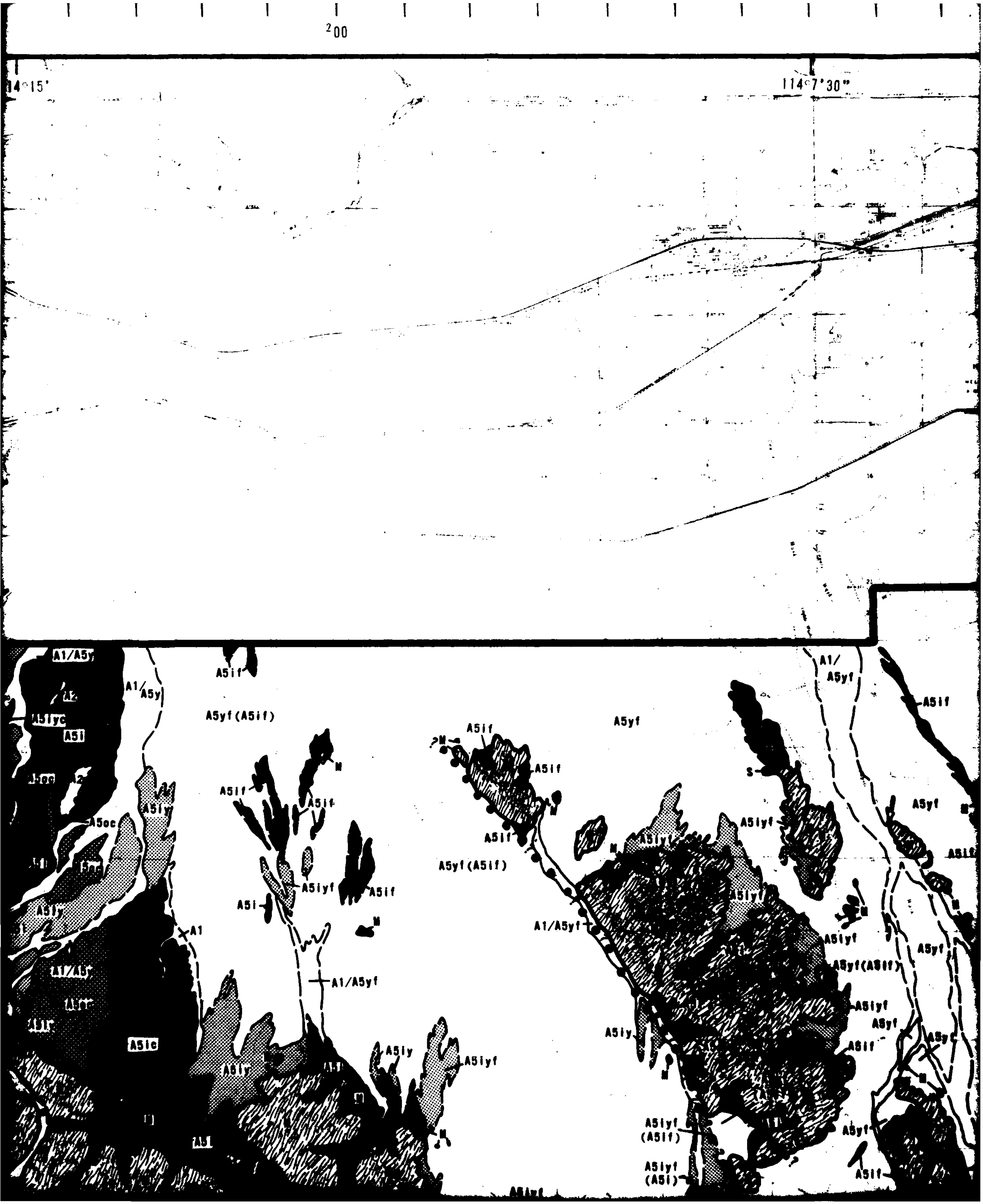
SOIL PROFILES
LECHUGUILLA DESERT, ARIZONA

MX SITING INVESTIGATION DEPARTMENT OF THE AIR FORCE - SAMSO	DRAWING 3

FUGRO NATIONAL, INC.

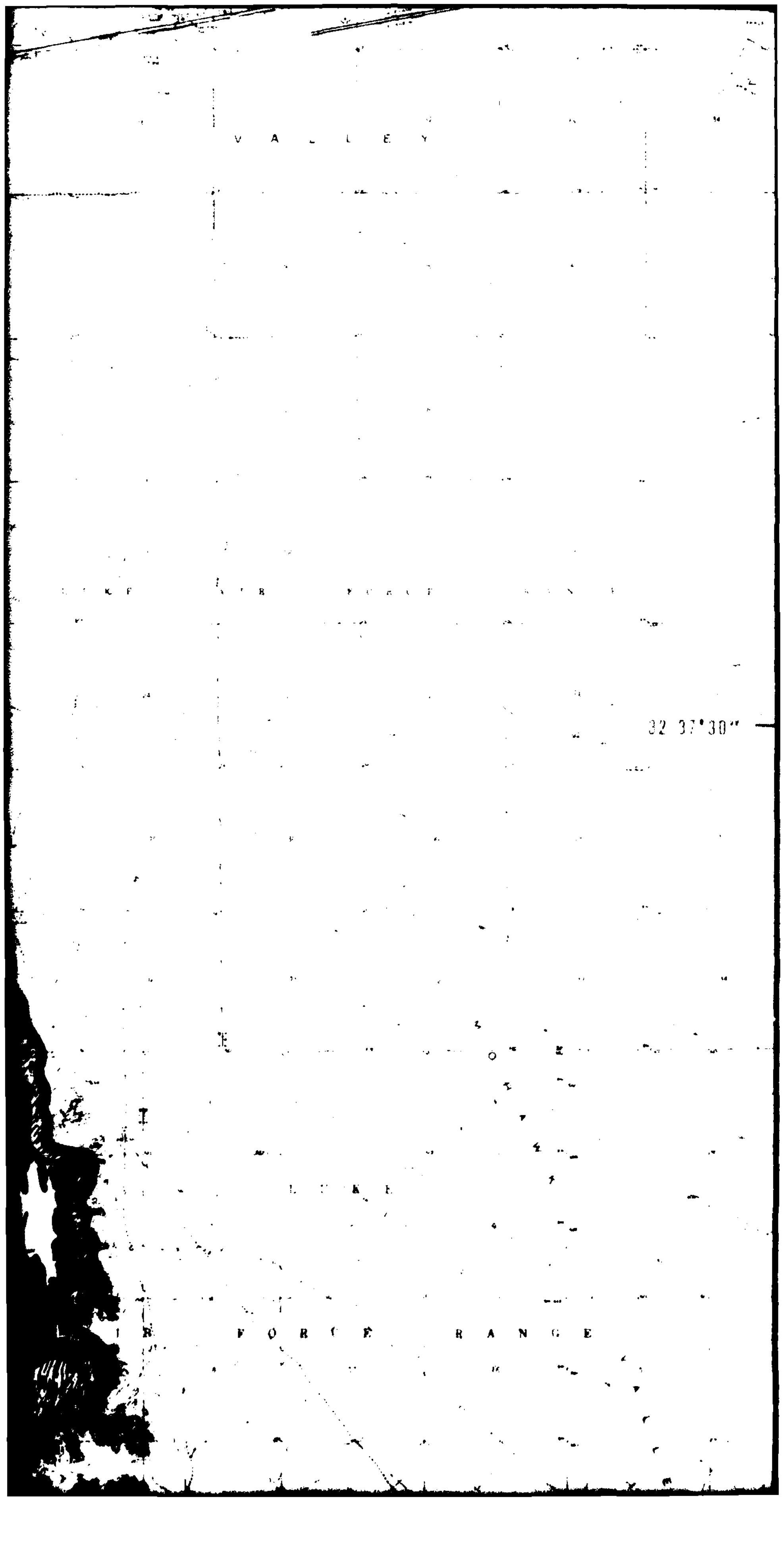


190
114°15'
36°20
32°37'30"
A5ly
A5l
A1/A5y
A5lyc
A5ec



200
114°7'30"
A1/A5y
A5if
A5yf(A5if)
A5yf
A1/A5yf
A5lyc
A5i
A5oc
A5iy
A5iyf
A5i
M
S
A1
A1/A5yf
A5ic
A5yf(A5if)
A5iyf
A5iy
A5yf
A5iyf
(A5if)
A5iyf
(A5i)

114 00'
A5iy
A1
S
A5iy
A5if
A5yf
A5if(S)
A5iy
A5if
A5if
A5yf (A5if)
A5yf
M
A5if
A5if
A5if
A5i
A3s
A5yf (A5if)
A5yf
A5if
A5if
A5iy
A5if
A5iyf
A5iy
A5i
A5yf (A5if)
A1/A5yf
A5i
A5i
A5if
A5yf
A5if
A5if
A5iyf
A5if
A5if
A5if
A5iy


V A L L E Y
32 37'30"
L U K E
F O R C E   R A N G E

EXPLANATION

SURFICIAL BASIN-FILL UNITS

Stream Channel Deposits (A1); Loose to medium dense, moderately to well sorted sand with minor amounts of silt- and gravel-sized material; deposits become finer grained in the downstream direction.

Terrace Deposits (A2); Medium dense to dense, well sorted silt and clay with lenses of sand and gravel.

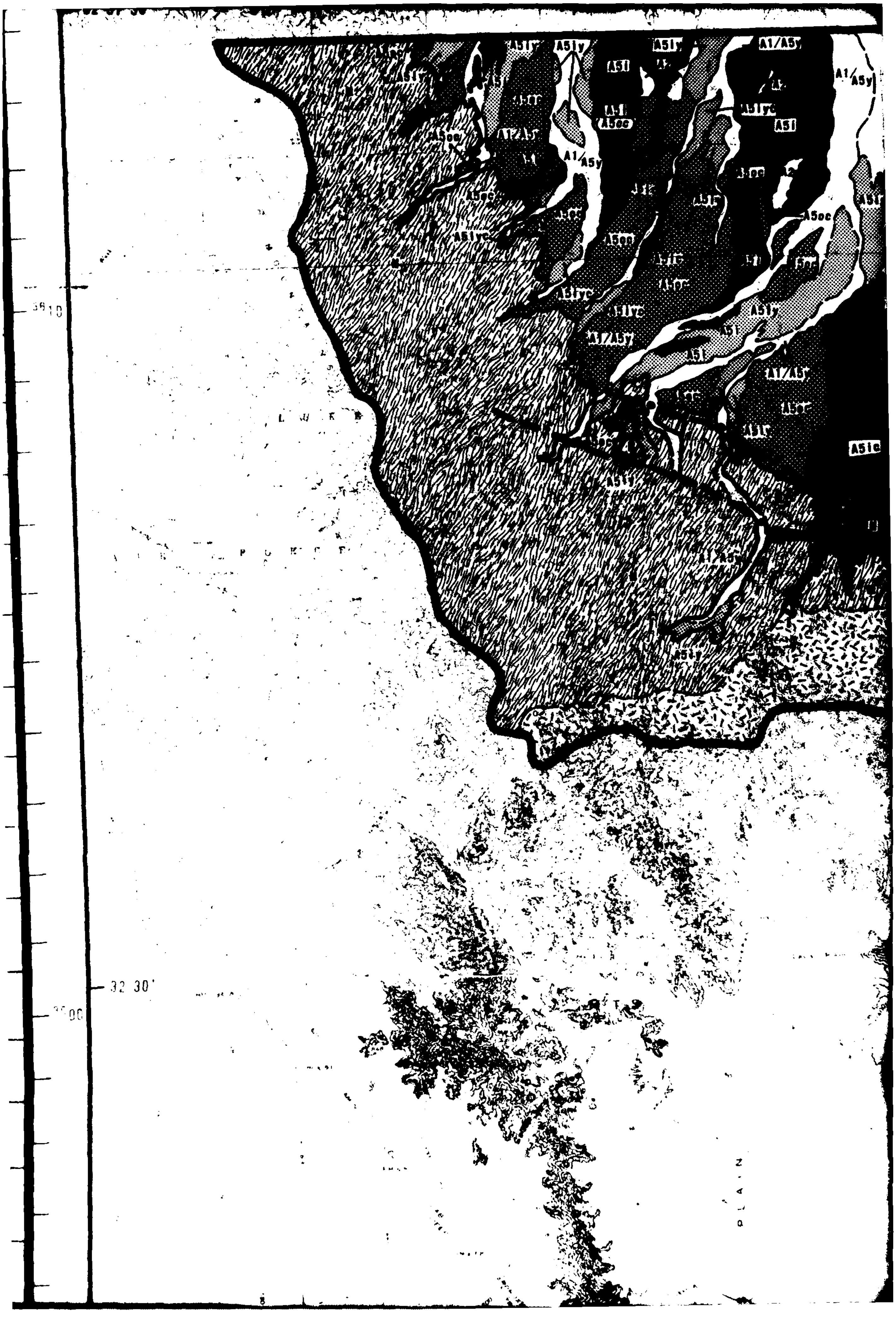
Eolian Sand Deposits (A3); Loose to medium dense, well sorted, fine to medium grained sand to silty sand deposited as thin sheets (A3s) or dunes (A3d).

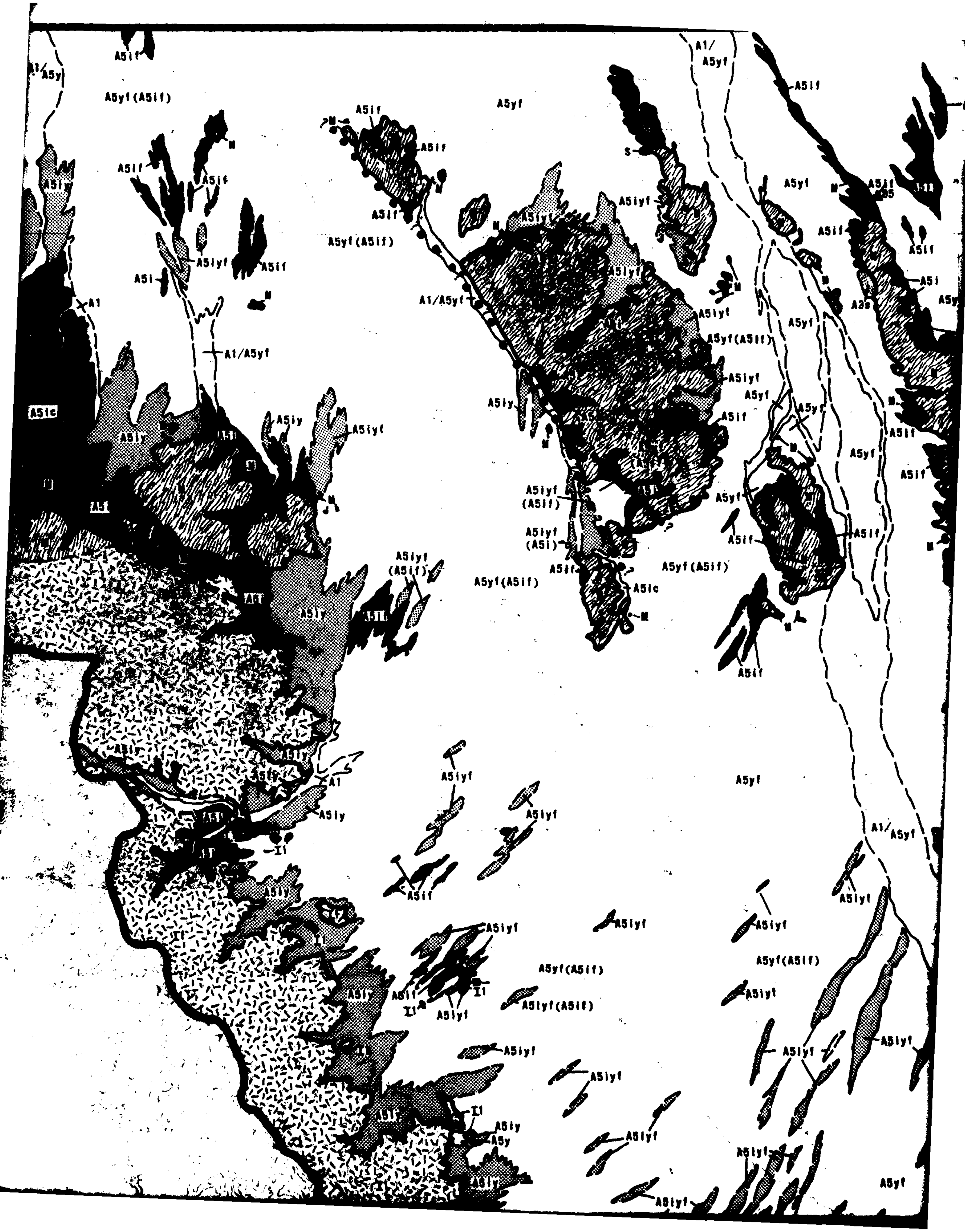
Alluvial Fan Deposits (A5); Loose to dense, poorly sorted sand and gravel with varying amounts of silt, cobble, and boulder-sized material. Deposits become finer grained with distance from the source area (proximal to distal end); relative age is indicated by lower case letters.

A5y, A5yf	–	younger, weak to no cementation, no to poor pavement and no patina
A5iy, A5iyf, A5iyc	–	intermediate-younger, weak to no cementation, no to well developed pavement and patina
A5i, A5if, A5ic	–	intermediate, weak to strong cementation, poor to well developed pavement, no to well developed patina.
A5oc	–	older, moderate to strong cementation, poor to well developed pavement, no to well developed patina.

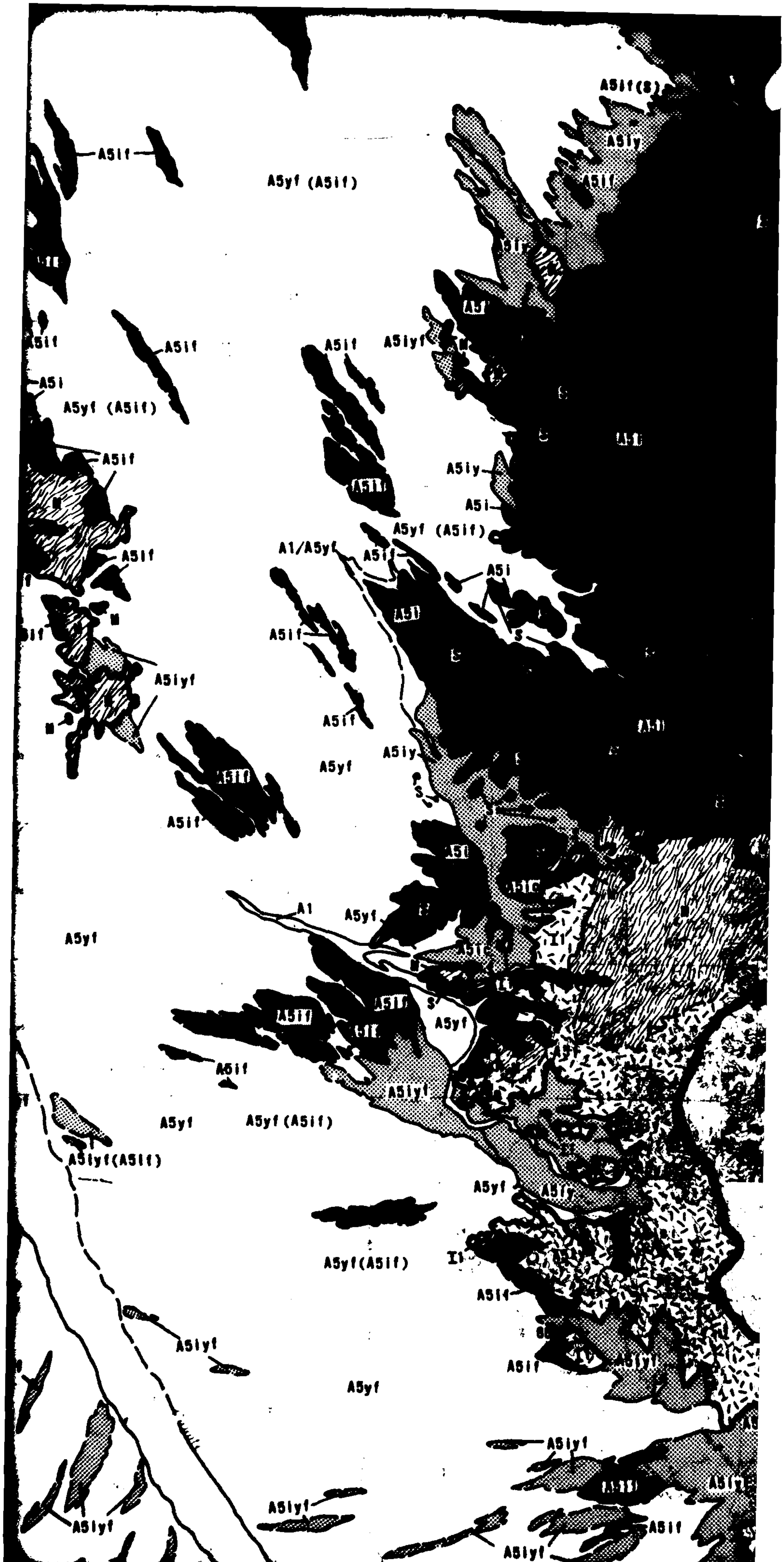
Modifying letter (f) designates predominantly finer-grained (less than 3 inches; 76mm) material; (c) designates predominantly coarser-grained material. Absence of a modifying grain-size letter indicates a gradation from coarser to finer-grained within the fan segment or data were insufficient to differentiate.

A3s/A5yf – Mixed surficial basin-fill units.


A5ly
A5l
A1/A5y
A5ly
A5oc
A5lyc
A5lyc
A5lyc
A1/A5y
A5ly
A5l
A1/A5y
A5oc
A5lyc
A5ly
A5lc
A1/A5y
A5ly
32 30'



A5if
A1/A5y
A5yf(A5if)
A5yf
A1/A5yf
A5if
M
A5if
A5if
A5iy
A5if
A5if
S
A5iyf
A5yf
A5if
A5iyf
A5if
A5i
A5yf(A5if)
A5if
M
A5iyf
A5if
A1
A1/A5yf
A5iyf
A5yf(A5if)
A5i
A3s
A5yf
A1/A5yf
A5iyf
A5ic
A5iy
A5iy
A5iyf
A5iy
A5iyf
A5yf
A5if
A5yf
A5if
A5iyf
(A5if)
A5iyf
(A5i)
A5if
A5yf(A5if)
A5iyf
(A5if)
A5yf(A5if)
A5if
A5ic
M
A5if
A5iy
A5iy
A5iy
A1
A5iy
I1
A5iyf
A5iyf
A5if
A1/A5yf
A5yf
A5iy
A5iyf
A5iyf
A5iyf
A5iyf
A5yf(A5if)
I1
A5yf(A5if)
A5if
A5iyf
A5iyf(A5if)
A5iyf
A5iyf
A5iyf
A5iyf
A5iyf
I1
A5iy
A5y
A5iyf
A5iyf
A5iyf
A5iy
A5yf


A5if(S)
A5iy
A5if
A5yf (A5if)
A5if
A5yf (A5if)
A5i
A5if
A5iyf
A5iy
A5i
A5yf (A5if)
A1/A5yf
A5if
A5i
A5if
A5iyf
A5if
A5iy
A5yf
A5if
A1
A5yf
A5yf
A5yf
A5if
A5iyf
A5yf
A5yf (A5if)
A5iyf(A5if)
A5yf
A5iy
A5yf(A5if)
I1
A5if
A5if
A5iyf
A5yf
A5iyf
A5iyf
A5iyf
A5if
A5iyf

3613

A1 — Stream Channel Depo
minor amounts of si
downstream directio

3612

A2 — Terrace Deposits (A2
sand and gravel.

3611

A3s / A3d — Eolian Sand Deposits
sand to silty sand d

3610

Alluvial Fan Deposit
amounts of silt, cob
with distance from t
by lower case letter

3609

A5y — A5y, A5yf

3608

A5iy — A5iy, A5iyf, A5i

3607

A5i — A5i, A5if, A5ic

A5o — A5oc

3606

Modifying letter
76mm) material; (
of a modifying g
grained within th

3605

A3s/A5yf — Mixed s

A5yf(A5i) — Parenth
1.5m).

3604

3603

S — *Sedimentary (S)*; Predom
(massively to indistinc
dominantly quartz monzo

3602

I1 / I2 — Igneous; Intrusive (I1);

3601

Igneous; Extrusive (I2);

M — Metamorphic (M); Metamo
quartz, feldspar, bioti

3600

3599

GEOLOGIC CONTACT; Rock/
where line is dash
to limited extent)

3598

GEOLOGIC CONTACT; Withi

3597

FAULT; Approximately lo
queried where exis

3596

STRIKE AND DIP OF BEDDI

downstream direction.

Terrace Deposits (A2); Medium dense to dense, well sorted silt and clay with lenses of sand and gravel.

Eolian Sand Deposits (A3); Loose to medium dense, well sorted, fine to medium grained sand to silty sand deposited as thin sheets (A3s) or dunes (A3d).

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A5iy, A5iyf, A5iyc – intermediate-younger, weak to no cementation, no to well developed pavement and patina

A5i, A5if, A5ic – intermediate, weak to strong cementation, poor to well developed pavement, no to well developed patina.

A5oc – older, moderate to strong cementation, poor to well developed pavement, no to well developed patina.

Modifying letter (f) designates predominantly finer-grained (less than 3 inches; 76mm) material; (c) designates predominantly coarser-grained material. Absence of a modifying grain-size letter indicates a gradation from coarser to finer-grained within the fan segment or data were insufficient to differentiate.

A3s/A5yf – Mixed surficial basin-fill units.

A5yf(A5i) – Parenthetic unit underlies mapped unit at depths of 0 to 5 feet (0 to 1.5m).

ROCK UNITS

Sedimentary (S); Predominantly arkosic sandstone and granite-gneiss boulder conglomerate (massively to indistinctly bedded); cobble and boulder clasts in conglomerate are predominantly quartz monzonite, schist, and gneiss.

Igneous; Intrusive (I1); predominantly fine to coarse grained quartz monzonite.

Igneous; Extrusive (I2); predominantly basalt.

Metamorphic (M); Metamorphic complexes of gneiss and schist; mineral compositions of quartz, feldspar, biotite, muscovite, amphibole, and epidote.

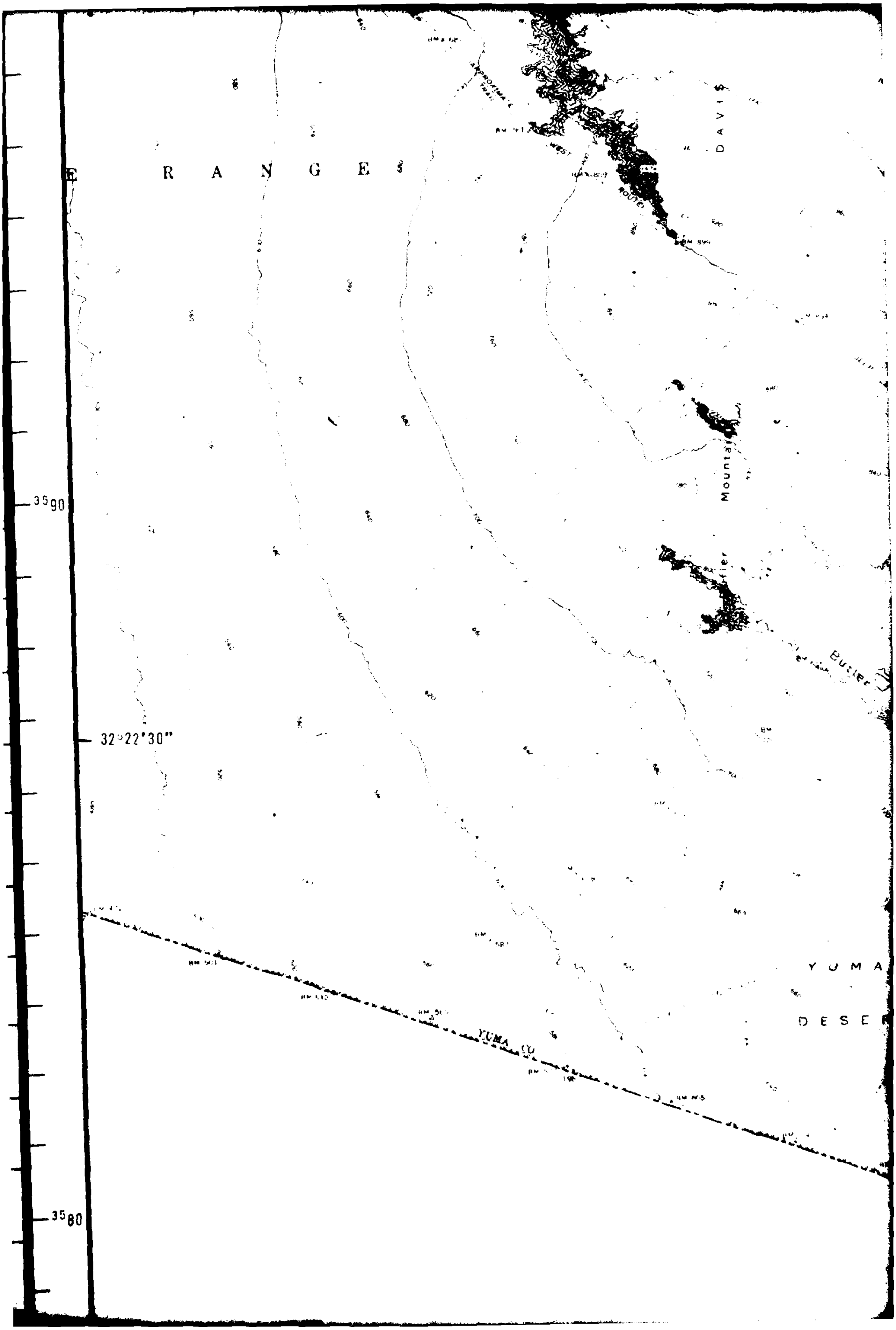
SYMBOLS

GEOLOGIC CONTACT; Rock/basin fill where line is solid, rock and colluvium/basin fill where line is dashed. (Colluvium cannot be illustrated at presentation scale due to limited extent).

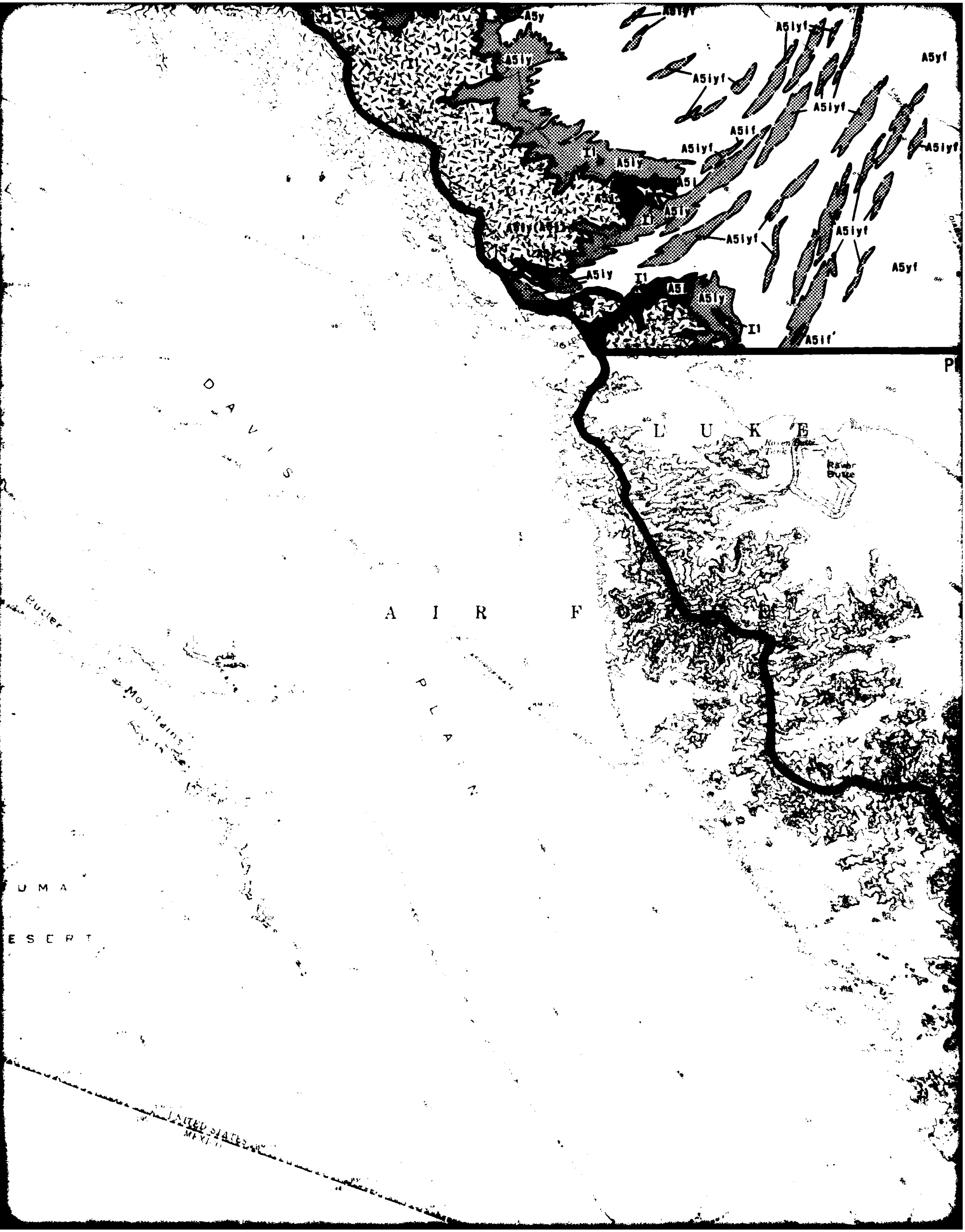
GEOLOGIC CONTACT; Within rock or basin-fill units; dashed where approximately located.

FAULT; Approximately located, dotted where concealed by surficial deposits, queried where existence uncertain.

STRIKE AND DIP OF BEDDING

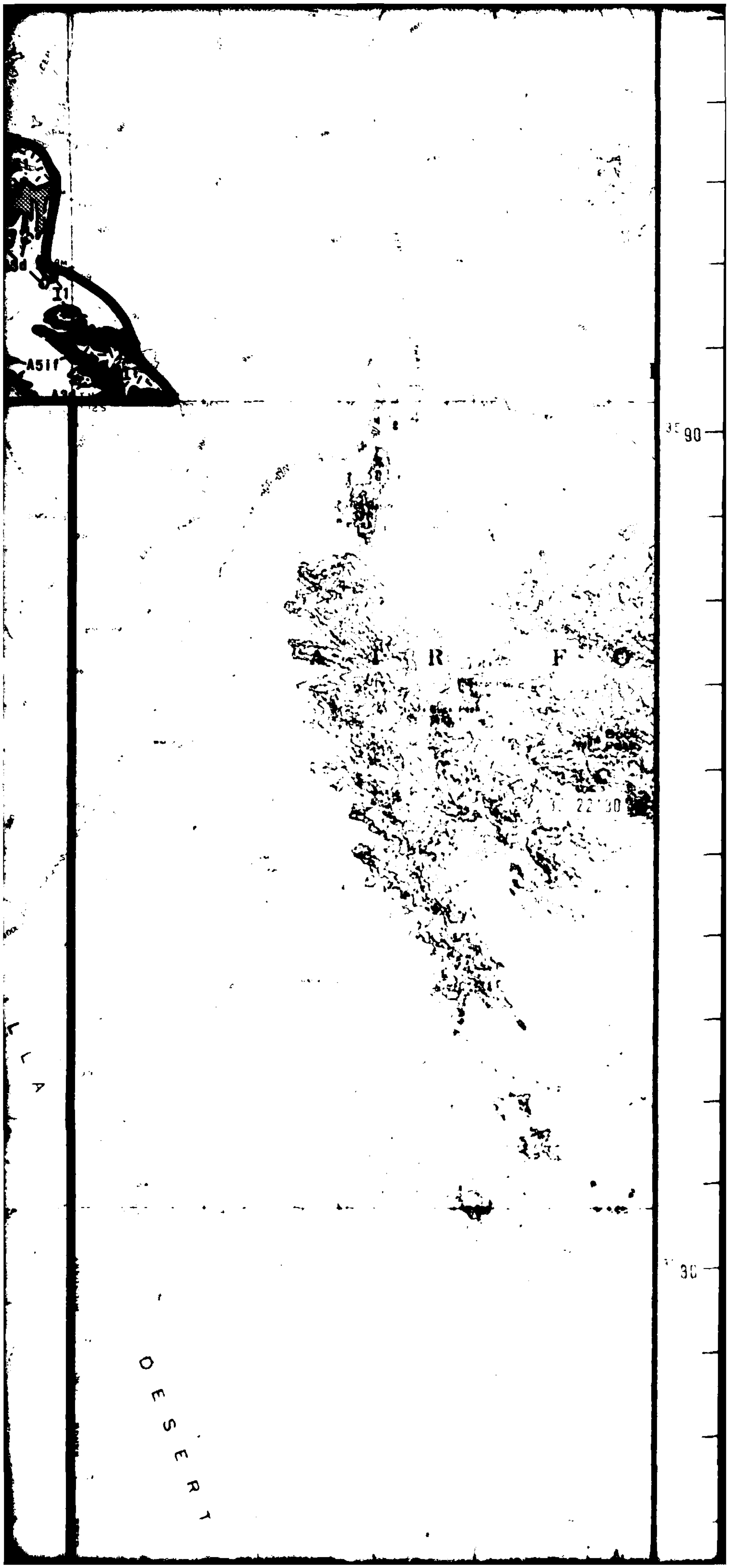


RANGE
DAVIS
Mountains
Butler
Butler
YUMA
DESE
YUMA CO
APPROXIMATE TRAIL
WEST ROUTE
35 90
35 80
32°22'30"



A5y
A5iyf
A5yf
A5iy
A5if
I1
A5i
A5iy(A5i)
PI
LUKE
AIR FORCE
Raven Butte Tank
Raven Butte
DAVIS PLAIN
Butler Mountains
YUMA DESERT
UNITED STATES
MEXICO

PROPOSED CABEZA PRIETA GAME RANGE EXTENSION



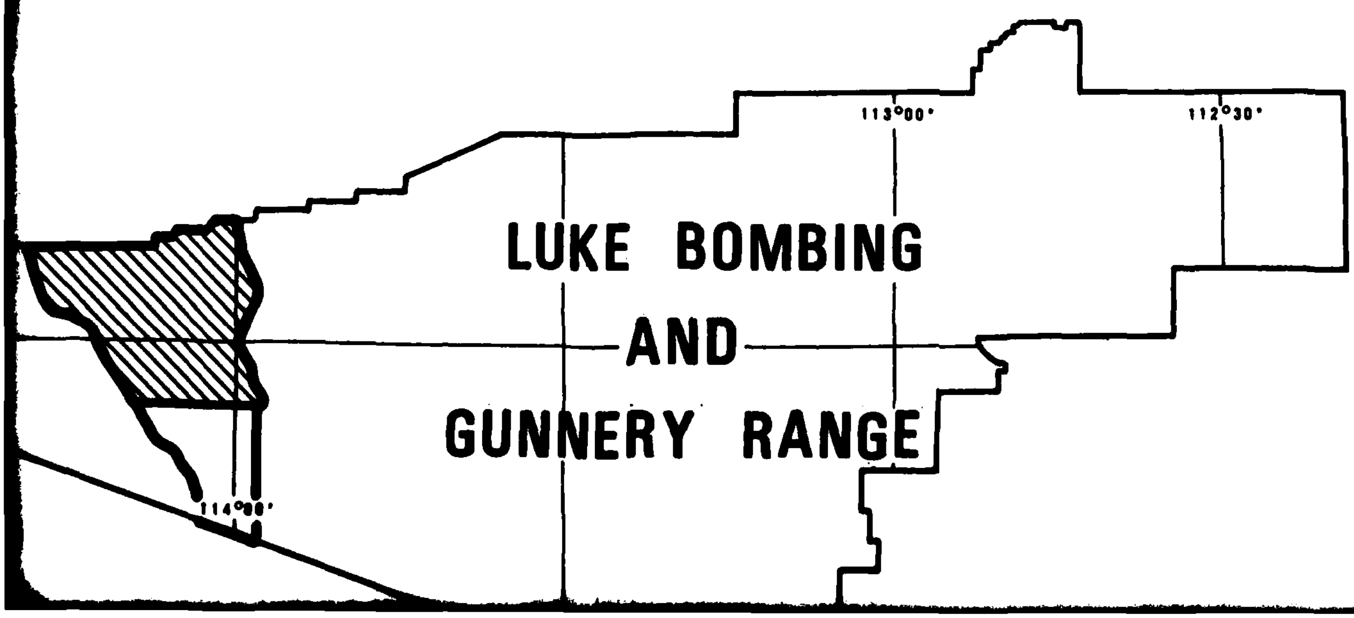
A511
A I R
DESERT
90
30

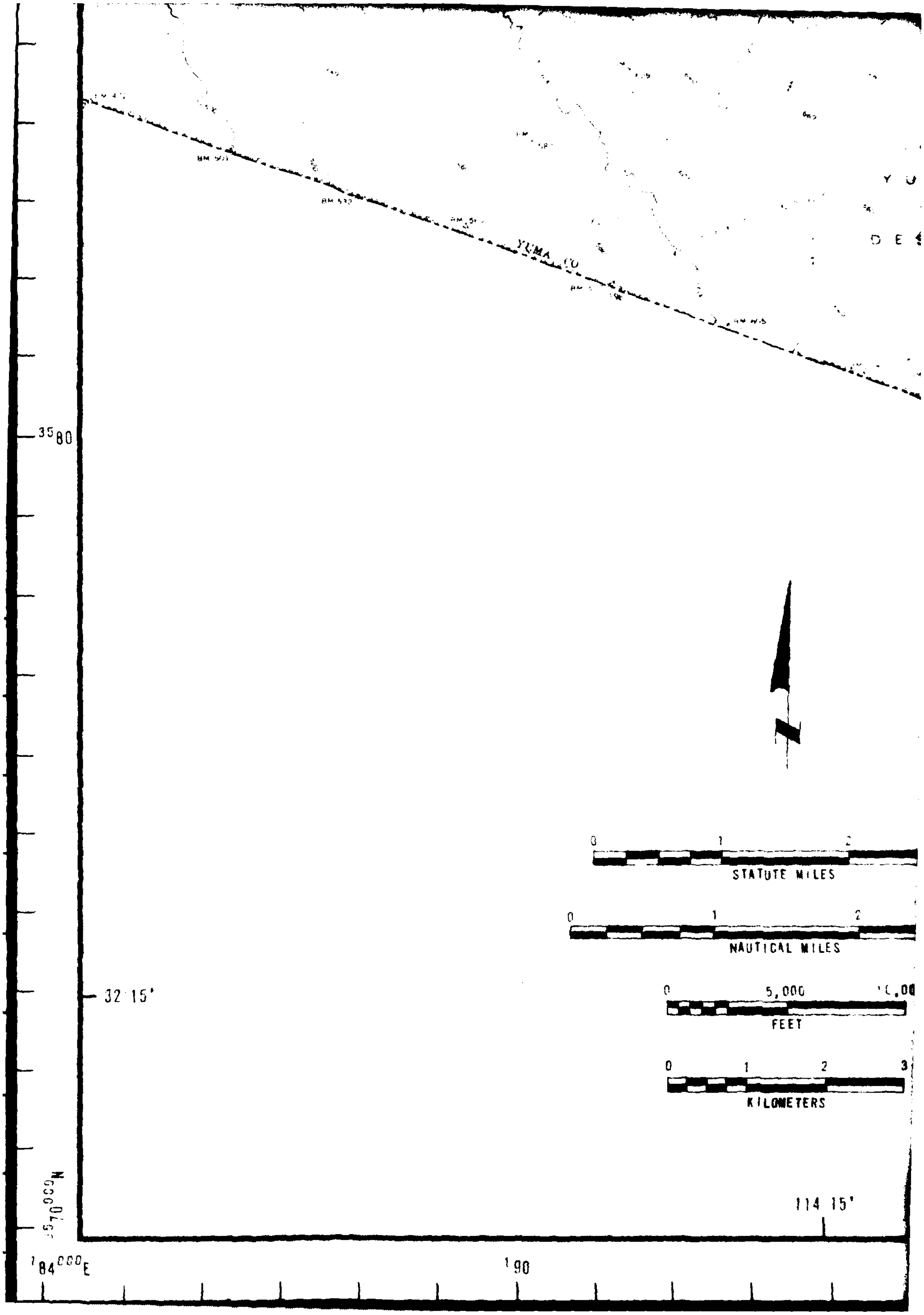
STRIKE AND DIP OF FOLIATION

STRIKE OF VERTICAL FOLIATION

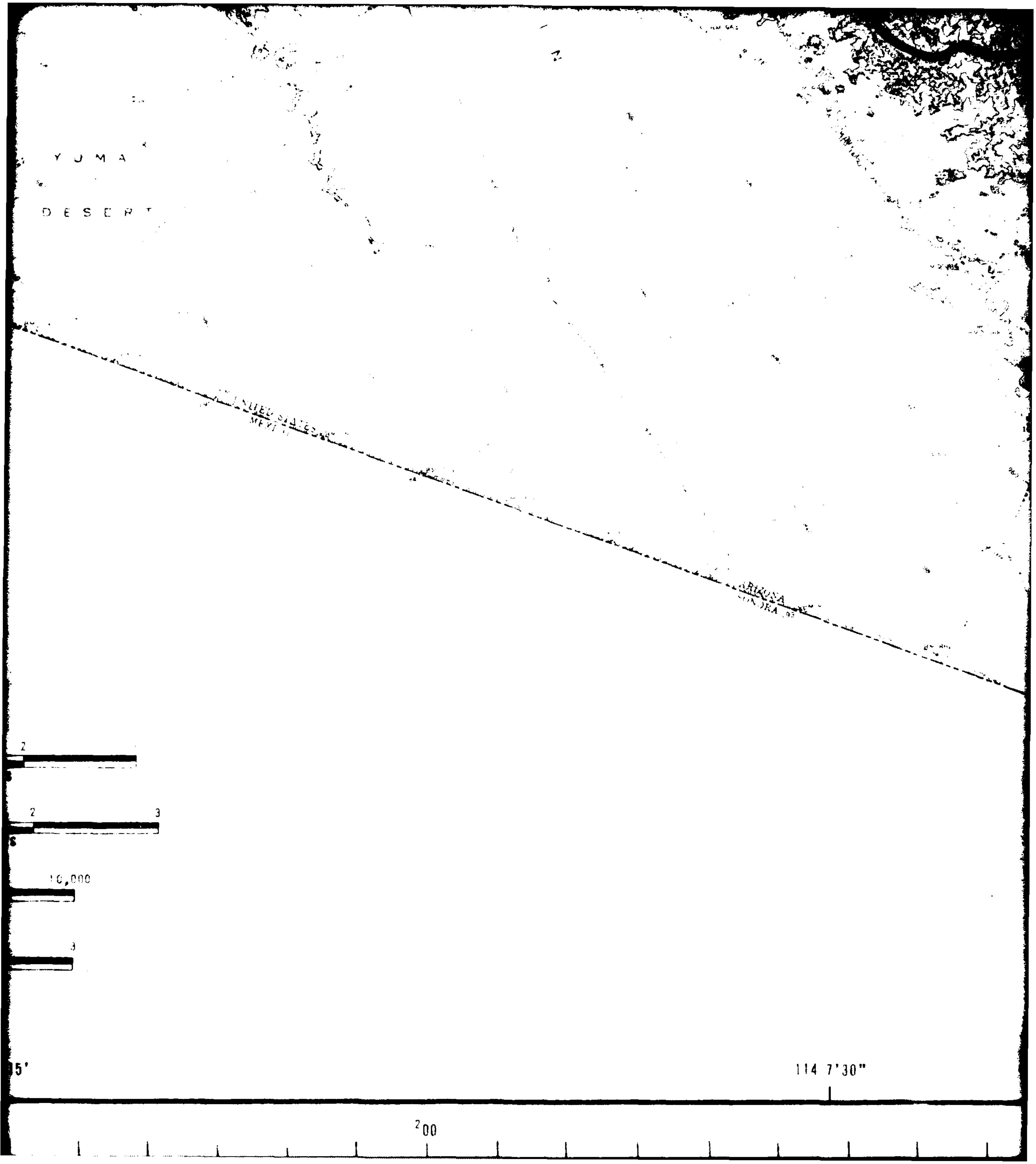
STRIKE AND DIP OF MAJOR JOINTS

STRIKE OF VERTICAL JOINTS



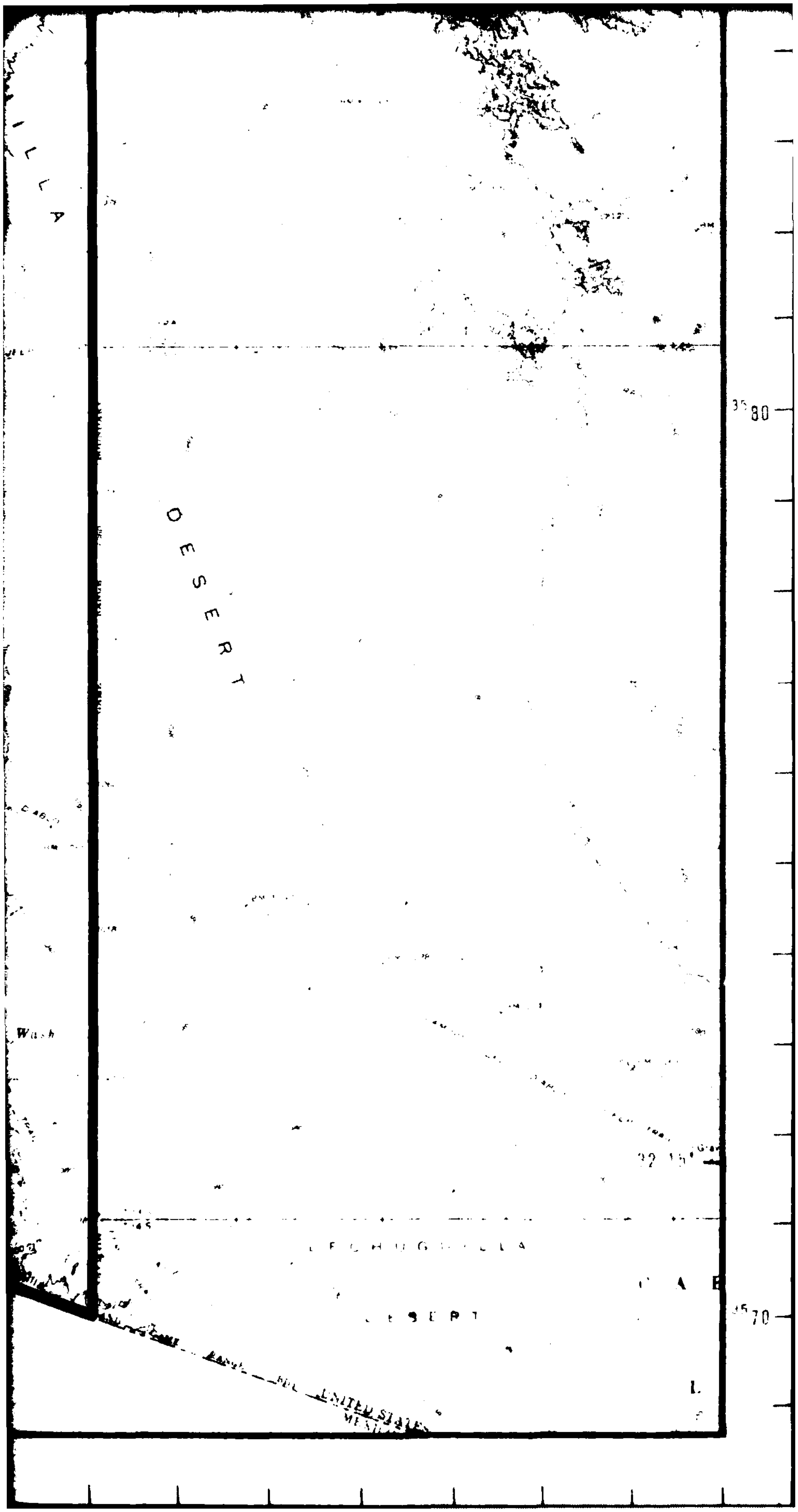


YUMA CO
3580
32 15'
STATUTE MILES
NAUTICAL MILES
5,000
FEET
KILOMETERS
114 15'
184000E
190

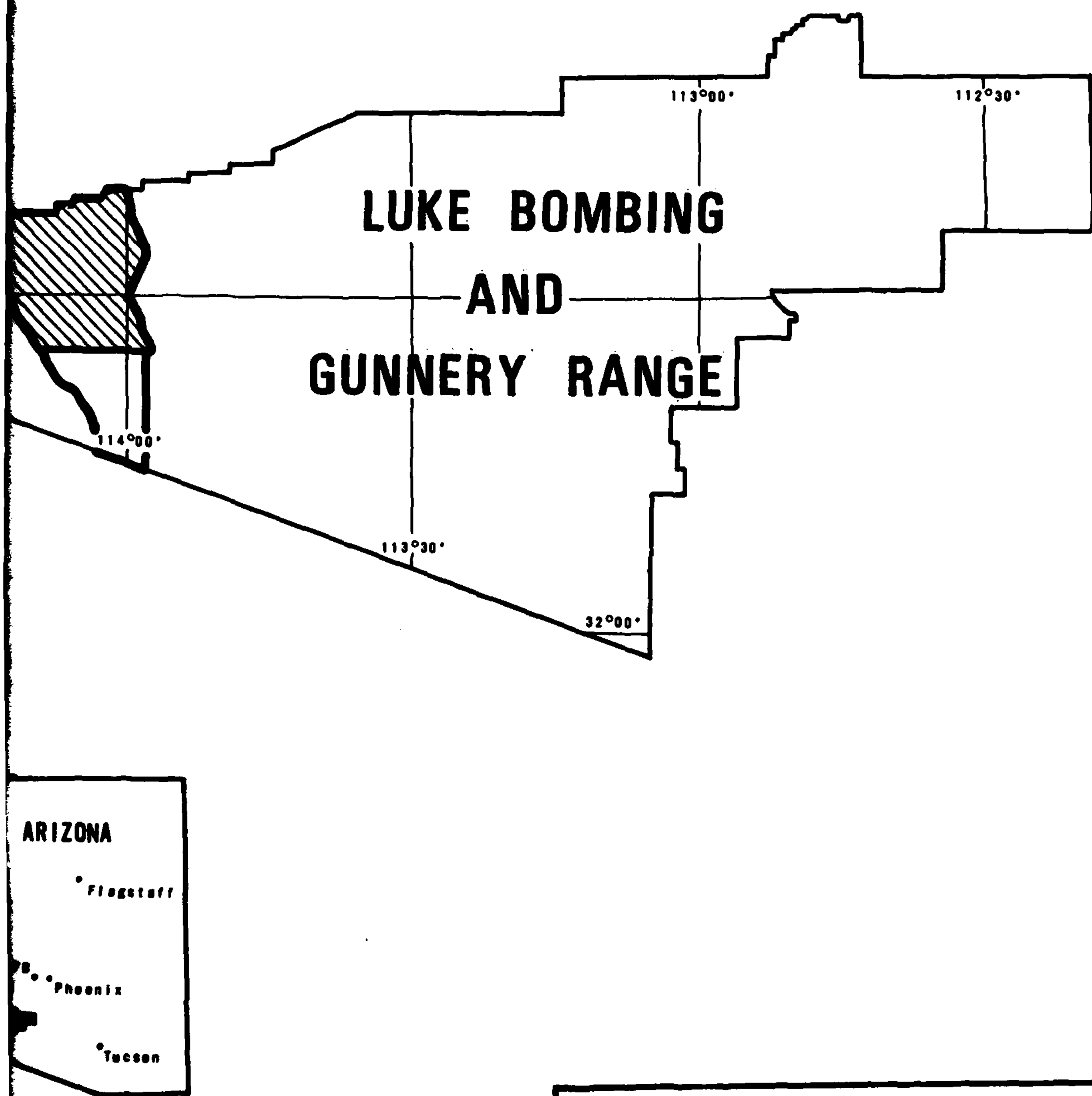


Y U M A
D E S E R T
ARIZONA
114 7'30"

G U I L L A
Coyote
Wash
114 00'
10
20



DESERT
Wash
UNITED STATES
80
70



GEOLOGIC MAP
LECHUGUILLA DESERT, ARIZONA

MX SITING INVESTIGATION DEPARTMENT OF THE AIR FORCE - SAMSO	DRAWING 2

FUGRO NATIONAL, INC.